AD NUMBER

AD368420

CLASSIFICATION CHANGES

TO

unclassified

FROM

confidential

AUTHORITY

Oct 1974 per DoDD 5200.10

CONFIDENTIAL

NRL Memorandum Report 754

SUMMARY OF NAVY STUDY PROGRAM FOR F4H-1 WEAPON SYSTEM

(Parameter Plots for Sparrow III Missile Attacks)

(UNCLASSIFIED TITLE)

VOLUME XV

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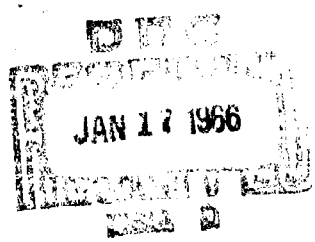
RADAR DIVISION

October 1962



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ABSTRACT

The Naval Research Laboratory is serving as technical director of the Navy's Air-to-Air Missile Study. The results are presented in a series of volumes under NRL Memorandum Report 754. This volume is the fifteenth in this series. The study to date has been primarily concerned with the system employing the F4H-1 aircraft, the AN/APQ-72 radar and the Sparrow III6a missile. This volume represents a continuation of the study results presented in preceding volumes. Examples of missile parameter variations, missile limits encountered and missile miss distance results are presented.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NRL Problem 53R05-04
BUWEPS Problem EL-42001

LIST OF FIGURES

SUMMARY OF NAVY STUDY PROGRAM FOR F4H-1 WEAPON SYSTEM

INTRODUCTION

The Bureau of Naval Weapons has a project with the Naval Research Laboratory to conduct system studies directed toward establishing the tactical use capability of the Navy's Air-to-Air Missile Systems. These studies are conducted under the technical direction of the Naval Research Laboratory with all inputs derived from Navy sources. To date, study effort has been primarily directed toward revealing the tactical use capability of the F4H-1 Weapon System. In support of this effort, NRL has contracted with Westinghouse Air Arm Division for analytical services. Recommendations and conclusions to be drawn from analytical results are a Navy responsibility, and in particular the responsibility of the technical director (NRL). This report is the fifteenth in a series directed toward revealing the tactical effectiveness of the F4H-1 Weapon System.

The Navy study has been, and will continue to be, a cooperative effort. Wherever possible duplication has been avoided. Input data for the study has been obtained from the government facilities which most logically would cover the particular field. For example, radar test data was obtained from NATC, Patuxent; Sidewinder performance data was obtained from NOTS, Inyokern; and Sparrow III seeker performance data was obtained from NMC, Pt. Mugu. In addition, the facilities of the various activities have been, in effect, pooled so that special talents and equipments can be employed. The results of NMC, Pt. Mugu simulator studies to ascertain the allowable launch error for Sparrow III, and the effects of hydraulic oil limits have been incorporated in the overall study. In addition, NMC has conducted tests to verify the vectoring accuracies and to determine if the field degradation applied to AI radar detection range in this study is valid. It is very important that everyone concerned recognize that a study such as this must be a team effort. It is just as important to continue this team effort on future studies under the Sparrow III-6b and other programs.

The study results, to date, have been presented in Vols. I through XIV of this series (references 1 thru 12). The study effort covered by Volumes I thru X carries the system through to Sparrow III-6a missile launch. At this point it is assumed that, if the initial aircraft heading errors can be reduced to an acceptable launch error, the missile will fly perfectly to impact with the target. The probability of arrival to missile launch results presented in these preceding volumes are based upon this assumption.

The study effort covered by Volumes XI thru XV is primarily concerned with the launch and missile guidance phases of the attack. The investigation of these phases of the attack has been divided into three parts and have been reported on in the same fashion. These three parts are:

1. Investigation of the tactical effectiveness of the F4H-1 system when employing the Sp III 6a missile as defined at the start of the Navy's Study. This missile is referred to throughout the text as the unimproved Sp III 6a.

2. Investigation of the sensitivity of system performance to Sp III 6a parameter variations.

3. Investigation of the tactical effectiveness of the F4H-1 system when employing the Sp III 6a missile as defined today. This missile will be referred to as the improved Sp III 6a. Miss distance results for the missile associated with the investigation of each of the above three phases are given in Vols. XI, XIII and XIV. This volume presents tables of initial conditions for a selection of the runs investigated; repeats miss distance results for this selected group of runs; presents tables of limits encountered during the missile flights on these runs; and presents selected samples of tables and plots of missile parameter variations during the missile flight for co-altitude and pull-up attacks.

INPUT DATA

The input conditions related to the subsystem performance and to the tactical situation have been detailed in preceding volumes. Only those items pertinent to the results presented in this volume will be repeated here.

Sp III 6a Missile

The Unimproved Sparrow III missile which has been used in the simulation program of the Navy's Air-to-Air Missile Study is detailed in the Appendix to Volume XI. For the most part, this information is also valid for the latest version (improved) of the Sparrow III 6a. There are areas which have changed and these changes were included in the Navy Study of the improved missile (Volume XIII). When the Sp III 6a is referred to in this text as the improved Sp III 6a the basic differences from the unimproved Sp III 6a are as follows:

Equation 4 in the Appendix to Volume XI gives the average incremental missile velocity as

$$V_{\delta} = 800 \left[1 + 0.41 (1 - P/P_{SL})\right]$$

P = pressure at altitude

P_{SL} = pressure at sea level

For the improved missile this equation is changed to

$$V_{\delta}' = 1000 \left[1 + 0.3 (1 - P/P_{SL})\right]$$

Equations 5 and 6 of the Appendix to Volume XI give the azimuth and elevation steering error equations as

$$\varepsilon_a = \frac{57.3 \left[V_{\sigma} \sin\lambda_a + R \frac{\omega_K}{17S}\right]}{2300}$$

ε_a = azimuth steering error
λ_a = azimuth gimbal angle
R = range
ω_k = azimuth line of sight rate

$$\varepsilon_e = \frac{57.3 \left[-V_{\sigma} \sin\lambda_e \cos\lambda_a - R \frac{\omega_j}{17S}\right] - 0.48\alpha}{2300}$$

ε_e = elevation steering error
λ_e = elevation gimbal angle
ω_j = elevation line of sight rate
α = angle of attack

For the improved missile these equations are changed to

$$\mathcal{E}_a = \frac{57.3\left[V_o \sin\lambda_a + \frac{R_{DM}}{1+S}\right]}{3400}$$

$$\mathcal{E}_e = \frac{57.3\left[-V_o \sin\lambda_e \cos\lambda_a - \frac{R_{DM}}{1+S}\right] - 0.48\alpha}{3400}$$

Table I gives the Sparrow III autopilot gains used in the Navy's Study of the unimproved Sp III 6a. In the latest version of the Sparrow III 6a, T_3 is changed to 0.3 secs for altitude bands C and D.

The Sparrow III autopilot and seeker block diagram is given by Fig. 1. On this block diagram, Block A is shown to have a transfer equation having the form of

$$\frac{50}{1+0.5_s}$$

In the latest version (improved) of the Sparrow III 6a, this block is changed to include a shaping network and the resulting transfer equations take the form of

$$\frac{45\left[\frac{P}{50}+1\right]\left[\frac{P}{266}+1\right]}{\left[\frac{P}{18.62}+1\right]\left[\frac{P}{5.81}+1\right]} \quad \text{(pitch channel)}$$

$$\frac{45\left[\frac{P}{60.7}+1\right]\left[\frac{P}{292}+1\right]}{\left[\frac{P}{19.9}+1\right]\left[\frac{P}{5.8}+1\right]} \quad \text{(yaw channel)}$$

The block labeled B on the diagram of Fig. 1 represents a limit and has the value of ± 80°/sec. In the latest version of the Sparrow III 6a this limit is changed to ± 100°/sec. The block labeled E also represents a limit and has the value 1.0° ± 1.25°. This is changed to 0° ± 2.25°.

TABLE I

SPARROW III AUTOPILOT PARAMETERS

t ≙ TIME FROM LAUNCH (TIME FROM END OF STROKE)

t_1 ≙ UNLOCK TIME = (0.4 - 0.08) SEC

t_2 ≙ END-OF-BOOST TIME = (2.22 - 0.08) SEC

t ≙ MISSILE SEEKER LOCK-ON TIME = (2.22 - 0.08) SEC

ALTITUDE CONDITION		A	B	C	D
ALTITUDE		SL-17K	17-32K	32-46	>4GK
τ_3 (SEC)		.15	.15	0.4	0.4
τ_5 (SEC)	YAW	4.93	3.17	1.70	1.09
	PITCH	3.87	2.49	1.33	.857
K_5 (°/g SEC)		3.57	5.56	10.5	16.3
τ_8 (SEC)		0.0063	0.0063	0.008	0.008
G_2 (°/°/SEC)		$\frac{1.14}{1+.25S}$	$\frac{1.14}{1+12.5S}$	$\frac{3.43}{1+.25S}$	$\frac{3.43}{1+12.5S}$
K_8 (°/°/SEC)		0.054	0.110	0.21	0.43

Radar Analyses

The AI radar performance used in this phase of the study corresponds to that predicted for the AN/APQ-72 (XN-3). The 85% probability of detection range for this radar against a B-47 size target flying at M 1.6 at 50,000 ft. where $V_T/V_F = 0.8$ is shown by Fig. 1 of ref. 9. Head-on, this radar has an 85% probability of detection at approximately 19 n. mi. when the expected 10 db of field degradation is used. The radar has gimbal limits of $\pm$ 57° in azimuth and elevation. It is currently estimated that these gimbal limits will actually be $\pm 60^{\circ}$. This change has not been incorporated in the study to date. A B-47 size target is used throughout this study.

Aircraft Analyses

The basic performance of the F4H-1 aircraft has been detailed in Vol. II of this series. Changes in this performance have occurred during the study period covered by this report. However, these changes have not resulted in significant changes in system analyses results. Details of the performance changes which have occurred and which are now being used in the simulation program are given in Volume XII of this series (reference 10).

GEOMETRY

The attack geometry for the fighter aircraft is shown on figure 2. The defined quantities will be used later in describing the conditions at missile launch.

Typical missile guidance geometry is shown by figure 3. Parameters shown on this chart which will be subject of investigation are:

R_{F-M} = Fighter to missile range

R_{M-T} = Missile to target range

R_{F-T} = Fighter to target range

H_M = Missile altitude

H_F = Fighter altitude

V_M = Missile velocity

V_F = Fighter velocity

V_T = Target velocity

λ_m = Missile lead angle

In addition the following parameters are of interest:

$\dot{R}_{F-M}$ = Fighter to missile range rate

$\dot{R}_{M-T}$ = Missile to target range rate

$\dot{R}_{F-T}$ = Fighter to target range rate

λa = Missile antenna azimuth gimbal angle

λe = Missile antenna elevation gimbal angle

w_k = Missile azimuth line of sight rate

w_j = Missile elevation line of sight rate

εa = Missile seeker azimuth look-angle error

εe = Missile seeker elevation look-angle error

α = Missile angle of attack

ϕ' = Missile roll angle

ϕ'' = Fighter roll angle

Δ_T = Total missile wing movement

Δy = Deflection of missile yaw wings

Δp = Deflection of missile pitch wings

MISSILE PARAMETER INVESTIGATION

The results of missile miss distance analyses have been detailed in preceeding volumes (ref. 7, 9, and 11). Particular missile runs (flights) which have been selected from the many used to get these miss distances, will be investigated in terms of missile parameter variations. These parameters are discussed in detail in the following sections.

Table II gives the conditions at missile launch for the fighter courses to be used in this investigation. Two fighter courses were selected for co-altitude attack with the unimproved Sp III 6a missile, two for pull-up attacks with the unimproved Sp III 6a missile and two for pull-up attacks with the improved Sp III 6a missile. The first column of Table II gives the box in the detection and probability grid (see fig. 2 of Vol. XI) from which the intercept runs originated. For the co-altitude samples boxes G-3 and D-1 were used. For the other two cases boxes E-1 and C-5 were used. The second column of this table gives the launch range condition. For the samples presented here all launches were at maximum aerodynamic range (Rmax). The next three columns give the X, Y, Z components of range to the target at launch. The next column gives the launch altitude of the interceptor aircraft. Columns 7 and 8 give the azimuth (E_{az}) and elevation (E_{el}) components of the steering error at missile launch. The final two columns give interceptor and target velocities at missile launch.

The following sections will discuss each of the two groups of runs for the three tactical situations given on Table II separately starting with the co-altitude attacks. Missile miss distances will be described first. This will be followed by a discussion of missile limits encountered during the flight. Finally a set of typical parameter plots will be presented.

TABLE II INITIAL CONDITIONS AT MISSILE LAUNCH

CO-ALTITUDE ATTACKS UNIMPROVED SP III 6a MISSILE

Fighter Course	Launch Range Ft	Rx Ft	Ry Ft	Rz Ft	Launch Alt. Ft	Steering Error		Vf	Vt
						ϵAZ Deg	ϵEL Deg	Ft/Sec	Ft/Sec
G-3	Rmax 32,744	31,340	-9,022	0	50,000	-3.40	9.97	1784	2005
D-1	Rmax 32,850	3,818	32,640	0	50,000	-0.014	0.241	1921	2005

INITIAL CONDITIONS AT MISSILE LAUNCH

PULL-UP ATTACKS UNIMPROVED SP III 6a MISSILE

Fighter Course	Launch Range Ft	Rx Ft	Ry Ft	Rz Ft	Launch Alt. Ft	Steering Error		Vf	Vt
						ϵAZ Deg	ϵEL Deg	Ft/Sec	Ft/Sec
E-1	Rmax 30,702	20,140	16,980	-15,760	49,236	-6.058	8.747	1776	1937
C-5	Rmax 37,179	34,540	10,650	-8,699	56,301	-0.011	0.074	1658	1937

INITIAL CONDITIONS AT MISSILE LAUNCH

PULL-UP ATTACKS IMPROVED SP III 6a MISSILE

Fighter Course	Launch Range Ft	Rx Ft	Ry Ft	Rz Ft	Launch Alt. Ft.	Steering Error		Vf	Vt
						ϵAZ Deg	ϵEL Deg	Ft/Sec	Ft/Sec
E-1	Rmax 30,554	19,890	16,980	-15,800	49,200	-4.743	7.064	1777	1937
C-5	Rmax 37,142	34,490	10,680	-8,722	56,278	-0.008	0.505	1667	1937

Co-Altitude Attacks - Unimproved Missile

The missile miss distance results for the first co-altitude attack, given in Table II are shown on figures 4a thru 4c. For this case (T9) the initial target aspect angle (angle with respect to the targets nose at the beginning of the interceptor run) is 15°. The box in the detection probability grid from which the run started is G-3. The fighter to target speed ratio, V_F/V_T = 1.0 and V_T = M 2.0. The altitude of the attack is 50,000 feet. These three figures present X - Y; X - Z and Y - Z projections of miss distance with respect to the geometrical center of the B-47 size target. On these figures the miss distances for 10 noise samples (shown by numbered circles) were investigated. The simulation was instrumented such that each of the 10 points on the same noise distribution could be selected as starting points for the missile launch and guidance investigation. As an example of how to interpret these figures referring to figure 4a the closest point of missile approach to the target in the X - Y phase for the run of noise sample 9 is approximately 6 feet in the X direction and 48 feet in the Y direction. The mean miss distance for the 10 noise samples examined is given by the solid square.

The missile limits encountered for this same situation are given on Table III. The first column on this table gives the noise sample involved. The second column gives the radial miss distance at the target. As an example, see noise sample 2. Radial missile miss distance was 70.57 ft. The third column gives missile time of flight. This is the time from launch to the time when the missile impacts with or passes the target. The times that the missile encountered "g" limits; (fixed limit in the autopilot - see Fig. 1) are given by the next column. The limiting value for the missile is 13.8 g's as an example referring to noise sample 8, it is seen that "g" limits were encountered at 2.8 seconds after launch. From this time until 6.8 seconds the missile flight path demanded less than the limiting "g's", at 6.8 seconds after launch "g" limits were encountered again and the missile rode the limit until the end of the flight. In those cases when an asterisk is used, it denotes the end of the missile flight.

The next column on Table III gives the times that missile seeker antenna gimbal limits were encountered. Gimbal limits of $\pm$ 46° are mechanized. As shown on Table III, missile gimbal limits were not a problem.

TABLE III

MISSILE LIMITS ENCOUNTERED

CO-ALTITUDE ATTACKS - R_{MAX} LAUNCH

V_T = 2005 H_T = 50,000
V_F = 1783.8 H_F = 50,000
T_O = 15° Box No. - G-3

Noise Sample	Miss (Ft)	(Sec)	TIME OF MISSILE LIMIT OCCURANCE (SEC)		
			"g" Limit	Missile Gimbal Limit	Wing Deflection Limit
1	44.46	7.134	(4.4) (6.8-*)		(0.4-0.6) (7.0-*)
2	70.57	7.165	(3.0) (5.6-5.8) (6.2) (7.0-*)		(0.4-0.6) (5.6)
3	33.65	7.137	(2.8) (7.0-*)		(0.4-0.6) (7.0-*)
4	21.63	7.128	(6.0) (*)		(0.4-0.6) (7.0-*)
5	58.52	7.141	(5.0)		(0.4-0.6) (*)
6	5.90	7.134	(3.6)((4.8) (5.2) (6.4) (7.0-*)		(0.4-0.6)
7	12.16	7.136	(6.6)		(0.4-0.6) (2.6) (*)
8	59.77	7.141	(2.8) (6.8-*)		(0.4-0.6) (7.0-*)
9	49.21	7.134	(5.8) (7.0-*)		(0.4-0.6)
10	10.03	7.139	(7.0-*)		(0.4-0.6)

*End of Missile Flight

As shown on figure 1, the missile mechanization includes a $\pm$ 20° wing (control surface) deflection limit. Thus it is of interest to investigate how often this limit was encountered on the simulated flights. The final column on Table III lists the times that these limits were encountered. It is interesting to note that on each case, limits were encountered at launch. Also in most cases the limits were encountered near the end of the run indicating that maximum maneuver was demanded.

From the runs associated with the miss distances described above, one run (noise sample 8) was selected and pertinent parameter variations were plotted. Figures 4d thru 4z give these parameter plots. The geometrical quantities plotted have been defined previously. A short discussion of each plot follows. Figure 4d shows the fighter to missile range (R_{F-M}) as a function of time. As is shown, after the initial missile acceleration period of approximately 2 seconds, the range variation is linear. The missile to target range (R_{M-T}) as a function of time is shown on figure 4e. Except for the slight curvature at the start of the missile flight (missile acceleration) the result is a straight line variation. Fighter to target range (R_{F-T}) is shown on figure 4f. The corresponding range rates are shown on figures 4g through 4i. Referring to 4g and 4h we see that the fighter to missile range rate ($\dot{R}_{F-M}$) and the missile to target range rate ($\dot{R}_{M-T}$) build up rapidly during the acceleration period of the missile and then gradual decay during the glide phase of the missile flight. The gradual change in fighter to target range rate ($\dot{R}_{F-T}$) shown on figure 4i is that associated with the lead pursuit course flown by the fighter.

The azimuth (λa) and elevation (λe) gimbal angles as a function of time are shown on figures 4j and 4k. The perturbations in the curves are due to system noises (launching transients, target noise, radome noise). As stated in the discussion of Table III, gimbal angle limits ($\pm$ 45°) are not encountered. The missile lead angle (λm) as a function of time is shown on figure 4l. Again the random variation is caused by noise. The azimuth (ω_{κ}) and elevation (ω_{γ}) missile antenna line of sight rates are shown on figure 4m and 4r. The same random variation occurs.

Missile velocity (Vm) as a function of time is shown on figure 4v. During the acceleration period of the missile flight, this velocity builds up from the launch velocity (interceptor velocity) and then gradually decays during the glide phase. The azimuth and elevation look-angle errors (εa and εe) for the missile are shown by the curves of figures 4p and 4q. Again, the perturbations are due to system noise. The missile angle of attack (α) as a function of time is shown on figure 4r. The angle of attack decays immediately after launch and then builds up rapidly to a peak of approximately 13° in the vicinity of one second. During the major portion of the flight, angle of attack

is influenced by system noise as shown by the oscillations. Near the end of the flight, angle of attack builds up rapidly again.

Missile (ϕ') and fighter (ϕ'') roll angles versus time are shown on figure 4s. At launch the roll angles, as expected, are the same. After launch the missile is rolled through 45°. This is reflected in the curves.

The g's commanded in the plane of the pitch and azimuth wings are given by figures 4f and 4u. In the early phases of the study of the unimproved missile mechanization the missile was limited to 13.8 g's or less. Referring to figure 4t it is seen that g limits are encountered at 2.8 seconds and again at 6.8 seconds to the end of the run.

Figures 4v and 4w show the commanded wing deflections on the pitch and azimuth wings. Mechanized wing deflection limits are $\pm$ 20°. Referring to these figures we see that limits are encountered at 0.4 to 0.6 seconds and again at 7.0 seconds to the end of the run.

The actual wing deflections are shown on figures 4x and 4y. Comparing these figures to figures 4t thru 4w one can get a complete history of commands, limits and responses. For example, we would expect the actual wing deflections to be high from 7 seconds to the end of the run since limiting deflections (+20°) are commanded. However at this time the missile is also g limited. Thus limiting wing deflections are not encountered.

Total wing movement (Δ_T) is shown on figure 4z. For this particular flight the plot of wing movement is essentially a linear function. This summation of wing movement can now be translated directly into oil consumption.

Another sample of co-altitude data resulting from use of the unimproved missile, is given by figures 5a, b, and c, Table IV and figures 5d through 5z. This group of data corresponds to the second family on Table II. The initial conditions are:

H_F = 50,000 ft.

V_T = M 2.0

$\frac{V_F}{V_T}$ = 1.0

γ_o = 15°

Box = G-3

Rmax Launch

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TABLE IV MISSILE LIMITS ENCOUNTERED

CO-ALTITUDE ATTACKS - R_{MAX} LAUNCH

V_T = 2005 Ft/Sec H_T = 50,000
V_F = 1920.9 Ft/Sec H_F = 50,000
γ_o = 60° Box No. - D-1

Noise Sample	Miss (Ft)	t_f (Sec)	TIME OF MISSILE LIMIT OCCURANCE (SEC)		
			"g" Limit	Missile Gimbal Limit	Wing Deflection Limit
1	26.88	14.136	(13.0) (13.8)	(13.0) (13.8)	(0.6) (*)
2	73.61	14.206	(13.8-*)	(11.6) (12.2) (13.6)	(0.6) (12.8) (14.2-*)
3	15.72	14.166	(14.0-*)	(13.2) (13.6-13.8) (*)	(0.6)
4	46.89	14.134	(13.8-*)		(0.6)
5	31.47	14.178	(13.4-13.6) (14.0-*)	(13.2) (13.6)	(0.6) (14.0-*)
6	29.92	14.131	(13.4) (14.0-*)	(12.2) (13.2) (13.6) (14.0)	(0.6) (14.0-*)
7	39.24	14.237	(14.0) (*)	(12.6) (13.6-13.8)	(0.6) (14-*)
8	53.67	14.225	(12.8-13.0) (13.6) (14.2-*)	(12.8) (13.4) (13.8)	(0.6) (13.2) (14.2-*)
9	23.68	14.167	(*)	(13.2) (13.6) (14.0)	(0.6)
10	38.37	14.187	(14.0-*)	(13.6)	(0.6) (*)
No Noise	2.17	14.066	(*)	(14.0)	(0.6)

*End of Missile Flight

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One difference in results from those presented for the previous case is that a no noise sample was also run. This is shown by the black circle on figures 5a through 5c. The term "no noise" applies only to the missile flight portion of the run.. Target noise only is neglected.

Pull-up Attack - Unimproved Missile

The second group of runs given on Table II are those resulting from using the unimproved Sp III missile in pull-up attacks. Miss distance results, limits encountered and parameter plots for these pull-up attacks are given by figures 6a through 6zz, Table V, figures 7a through 7zz, and Table VI. A brief description of the first of these two groups of results is given in the following sections.

The miss distance results for the ten noise samples are plotted on figures 6a through 6c. The mean miss distance is shown by a "■". The no noise results are shown by the "●". The initial aspect angle (γ_0) at AI radar detection is 0°. The fighter course started in box C-5 of the probability grid. $\frac{V_F}{V_T}$ = 1.0 where V_T = M 2.0. Target altitude is 65,000 feet. Fighter altitude at the beginning of the pull-up maneuver is 50,000 feet. The missile is launched at R_{max}.

Missile limits encountered are given on Table V. As in the case of the co-altitude flights described previously, gimbal limits are not a problem. Wing deflection limits and g limits are encountered in most of the runs. Referring to the second column on this table, it is seen that in general, miss distances are large.

The range relationships between fighter, target and missile vary linearly with time after the boost phase of the missile is completed as shown on figures 6d, 6e and 6f. The fighter to missile range rate is shown by figure 6g. After missile boost the range rate stays constant. This is due to the fact that the missile is gradually slowing down and so is the fighter while in the pull-up maneuver. Missile to target range rate is shown by figure 6h. As expected the range rate peaks up at end of boost and gradually decays as the missile slows down. The curve for fighter to target range rate given on figure 6i is the result of the pull-up; lead pursuit maneuver.

The antenna gimbal angles are shown by figures 6j and 6k. Missile lead angle is shown by figure 6l. The line of sight rates are shown by figures 6m and 6r. The perturbations are due to system noise.

TABLE V MISSILE LIMITS ENCOUNTERED

PULL-UP ATTACKS - R_{MAX} LAUNCH

V_T = 1937 Ft./Sec H_T = 65,000 Ft.
V_F = 2005 Ft. H_F = 50,000 Ft.
τ_o = 0° Box No. = C-5

Noise Sample	Miss (Ft)	t_f (Sec)	TIME OF MISSILE LIMIT OCCURANCE (SEC)		
			"g" Limit	Missile Gimbal Limit	Wing Deflection Limit
1	44.5	8.508	(7.0) (7.4-*)		(8.2-*)
2	50.3	8.540	(6.6-7.6) (8.0-*)		(7.2-7.6) (8.4-*)
3	162.8	8.500	(6.4) (7.2) (7.6-*)		(7.8-*)
4	81.7	8.508	(7.2-7.4) (8.2-*)		(8.4-*)
5	102.3	8.500	(7.6-*)		(7.6-*)
6	47.1	8.515	(6.8-7.0) (7.4-*)		(7.0) (*)
7	120.7	8.535	(7.2-*)		(7.2-7.6)
8	37.1	8.525	(5.4) (7.4-*)		
9	44.7	8.491	(6.4) (7.2) (7.8-*)		(8.2-*)
10	18.7	8.516	(7.4-7.8) (8.4-*)		(7.4-7.8)
No Noise	4.7	8.490	(8.2-*)		(8.0-*)

*End of Missile Flight

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TABLE VI

MISSILE LIMITS ENCOUNTERED

PULL-UP ATTACKS - R_{MAX} LAUNCH

V_T = 1937 Ft/Sec H_T = 65,000 Ft.
V_F = 2034 Ft/Sec H_F = 40,000 Ft.
τ_o = 45° BOX NO. = E-1

Noise Sample	Miss (Ft)	t_f (Sec)	TIME OF MISSILE LIMIT OCCURANCE (SEC) "g" Limit	Missile Gimbal Limit	Wing Deflection Limit
1	60.1	8.723	(7.6), (8.0-*)		(0.6), (7.8), (8.2-*)
2	94.1	8.776	(7.4), (8.0)		(0.6)
3	101.5	8.708	(7.6-*)		(0.6)
4	101.3	8.722	(7.6-*)		(0.6), (7.8)
5	77.2	8.718	(8.0-*)		(0.6), (8.6-*)
6	52.6	8.720	(8.0-*)		(0.6), (7.8), (8.2-*)
7	83.6	8.732	(7.0), (7.4), (7.8-*)		(0.6), (7.4-*)
8	52.4	8.724	(2.8), (8.4-*)		(0.6), (8.6-*)
9	69.4	8.725	(7.8-*)		(0.6), (8.2-*)
10	42.9	8.724	(7.8-*)		(0.6), (7.8)
No Noise	38.1	8.720	(8.2-*)		(0.6), (8.6-*)

*End of Missile Flight

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Missile velocity as a function of time is shown by the curve of figure 6o. The velocity history is as expected. It peaks up at end of missile boost and gradually decays during the rest of the flight.

Azimuth and elevation look-angle errors for the missile seeker are shown on figures 6p and 6q. These errors are essentially zero until the end of the run. The missile angle of attack time history of figure 6r shows many perturbations. These are due to systems noise. Missile and fighter roll angles are shown on figure 6s. The missile rolls the programmed (approx. 45°) roll angle during the early stages of the flight and continues at that angle. The fighter roll angle is that required by the pull-up; lead pursuit course.

Figures 6t thru 6y give commanded pitch and yaw g's; commanded pitch and yaw wing deflections; and actual pitch and yaw wing deflections.

Total wing movement as a function of time is shown by figure 6z. This is essentially a linear function.

Missile altitude versus time is shown on figure 6zz. For this particular case the missile rate of climb is essentially constant throughout the run.

Figures 7a through 7zz give another group of runs for the unimproved Sp III missile when used in pull-up attacks. Uses of the parameter plots and the tables are the same as described above for figures 6a through 6zz.

PULL-UP ATTACKS - IMPROVED MISSILE

The third "groups" of runs listed on Table II are those resulting from using the improved Sp III missile in pull-up attacks. The differences between the unimproved and improved missiles are detailed in the section of inputs as shown on page 3 .

Table II lists the initial conditions for the two families of pull-up runs investigated for the improved Sp III missile. The same two sets of initial conditions were used as described previously for the unimproved situation in order that a comparison of results could be made. Such a comparison has been described in detail in ref. 12. In general, referring to figures 8a thru 8c, 9a thru 9c and Tables VII and VIII, it is seen that the miss distances achieved for the improved missile are smaller than those realized for the unimproved missile. However, for the two cases given here there isn't a major improvement. The parameter plots given by figures 8d thru 8zz and 9j thru 9zz follow the same order as described for the preceding cases. The use of each is the same as that described previously.

ERROR IN Vo

Table IX gives the results of an investigation conducted to determine the error in computed Vo (average incremental missile velocity) Since Vo is used directly or indirectly in launch equation and steering computation, accuracy is important. On Table IX the launch conditions are repeated for each of the six families investigated. Under the heading of "Missile Simulation Results", there are four columns. The next column gives (Vo) the actual average incremental velocity between missile and launching aircraft. The next column gives the computed value of Vo. The error between actual and computed in percent is given by the last column. In general, for the cases presented here, the error is small.

TABLE VII

MISSILE LIMITS ENCOUNTERED

PULL-UP ATTACK (IMPROVED MISSILE) P_{MAX} LAUNCH

V_T = 1937 Ft/Sec H_T = 65,000 Ft.
V_F = 2005 Ft/Sec H_F = 20,000 Ft.
γ_c = 0° BOX NO. = C-5

Noise Sample	Miss (Ft)	t_f (Sec)	TIME OF MISSILE LIMIT OCCURANCE (SEC)		
			"g" Limit	Missile Gimbal Limit	Wing Deflection Limit
1	13.7	8.165	(2.8), (3.8-4.0) (4.4), (5.8), (6.8-7.0), (7.4-*)		(7.0), (7.6-7.8)
2	32.5	8.193	(2.6), (3.4), (5.0), (5.6-5.8), (6.4-6.8), (7.2-*)		(7.8), (7.4-7.6)
3	103.9	8.152	(6.0), (6.4), (7.2-*)		(7.8-*)
4	84.1	8.160	(2.8), (3.2-3.4), (6.2), (7.0-7.2), (7.6-*)		(7.8-*)
5	31.2	8.163	(5.8), (6.2), (6.6), (7.4-*)		(5.8), (7.4-7.6)
6	13.3	8.183	(2.6), (3.8-4.0), (6.4-7.0), (7.4-*)		(6.6-7.0)
7	46.1	8.191	(4.0-4.2), (5.8), (7.0-*)		(7.2) (*)
8	43.7	8.181	(2.8-3.0) (3.6), (4.0-4.2), (5.4), (7.4-*)		(4.2), (8.0)
9	27.6	8.151	(4.0), (4.8), (5.4), (6.2-6.4), (7.2), (7.6-*)		(4.2)
10	7.3	8.180	(4.2-4.4), (6.2), (7.4-*)		(4.4), (5.4), (6.2), (7.4-7.6)
No Noise	20.7	8.147	(8.0-*)		(7.8-*)

*End of Missile Flight

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TABLE VIII

MISSILE LIMITS ENCOUNTERED

PULL-UP ATTACKS - (IMPROVED MISSILE) R_{MAX} LAUNCH

V_T = 1937 Ft/Sec H_T = 65,000 Ft.
V_F = 2034 Ft/Sec H_F = 40,000 Ft.
γ_o = 45° BOX NO. = E-1

Noise Sample	Miss (Ft)	t_f (Sec)	TIME OF MISSILE LIMIT OCCURANCE (SEC)		
			"g" Limit	Missile Gimbal Limit	Wing Deflection Limit
1	62.2	8.255	(4.0), (5.8), (7.0), (7.4-*)		(7.0), (7.6-*)
2	96.8	8.314	(2.6), (5.0), (6.4-6.8) (7.4-*)		(5.4), (5.8)
3	95.9	8.240	(7.0), (7.4-*)		(8.0)
4	88.7	8.252	(4.0), (6.8), (7.4-*)		(6.8)
5	95.1	8.252	(4.0), (5.0), (5.8), (7.2-*)		(7.4), (7.8)
6	43.5	8.250	(2.6), (3.8), (7.0), (7.8-*)		(8.0-*)
7	73.9	8.262	(3.2), (7.0-*)		(7.2-*)
8	51.4	8.251	(2.8), (4.4), (5.4), (6.8-7.0), (8.0-*)		(6.8), (8.0)
9	94.5	8.247	(3.2), (4.2), (6.2-6.4), (7.4-*)		(8.2-*)
10	43.2	8.257	(4.2), (4.6), (7.6-*)		(7.6-7.8), (8.2-*)
No Noise	38.7	8.243	(8.0-*)		(*) *End of Missile Flight

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TABLE IX CO-ALTITUDE ATTACKS

LAUNCH CONDITIONS							MISSILE SIMULATION RESULTS			
Target Altitude H_T ($ftX10^3$)	Target Speed V_T (ft/sec)	Fighter Altitude H_F (ft)	Fighter Speed V_F (ft/sec)	Range R (ft)	Target Aspect Angle (deg)	Range Interlock Condition	Time of Flight t_f (sec)	Average Speed Relative to fighter (ft/sec)	Computed Vo (ft/sec)	Error in Vo (%)
50	2005	50,000	1920.9	32,860	83.33	R_{max}	14.166	1064.24	1090.25	-2.44
50	2005	50,000	1783.0	32,610	16.06	R_{max}	7.138	978.43	1090.25	-21.19

PULL-UP ATTACKS (UNIMPROVED MISSILE)

LAUNCH CONDITIONS							MISSILE SIMULATION RESULTS			
Target Altitude H_T ($ftX10^3$)	Target Speed V_T (ft/sec)	Fighter Altitude H_F (ft)	Fighter Speed V_F (ft/sec)	Range R (ft)	Target Aspect Angle (deg)	Range Interlock Condition	Time of Flight t_f (sec)	Average Speed Relative to fighter (ft/sec)	Computed Vo (ft/sec)	Error in Vo (%)
65	1937	49,236	1776.0	30,702	48.998	R_{max}	8.726	1136.74	1088.84	4.21
65	1937	56,301	1657.7	37,179	21.71	R_{max}	8.511	1112.50	1100.06	1.11

PULL-UP ATTACKS (IMPROVED MISSILE)

LAUNCH CONDITIONS							MISSILE SIMULATION RESULTS			
Target Altitude H_T ($ftX10^3$)	Target Speed V_T (ft/sec)	Fighter Altitude H_F (ft)	Fighter Speed V_F (ft/sec)	Range R (ft)	Target Aspect Angle (deg)	Range Interlock Condition	Time of Flight t_f (sec)	Average Speed Relative to fighter (ft/sec)	Computed Vo (ft/sec)	Error in Vo (%)
65	1937	49,199	1776.9	30,554	49.381	R_{max}	8.256	1287.4	1264.12	1.81
65	1937	56,278	1667.3	37141.6	21.789	R_{max}	8.169	1270.0	1274.42	-0.35

ACKNOWLEDGEMENTS

The data presented in this report represents the results, to date, of the Navy's Air-to-Air Missile Study Program. The analytical results, including those from which the figures were derived, are the results of the computational work underway at Westinghouse Air Arm Division. A large portion of the data reduction required for material presented in this volume was actually accomplished at Westinghouse and reviewed for accuracy by the Technical Directors. In addition, results of analysis underway at NMC, Pt. Mugu are included. The data from which the definition of the Sparrow III missile and the AN/APA-128 computer resulted were obtained from the Raytheon Mfg. Co. Definition of the aircraft performance resulted from the cooperative effort of the McDonnell Aircraft Company. Test data on AI radar performance was obtained from NATC, Patuxent. The authors would like to thank members of these activities for their cooperation.

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2. "Summary of Navy Study Program for F4H-1 and F8U-3 Weapons Systems, Volume II, Appendices to NRL Memorandum 754", Confidential.

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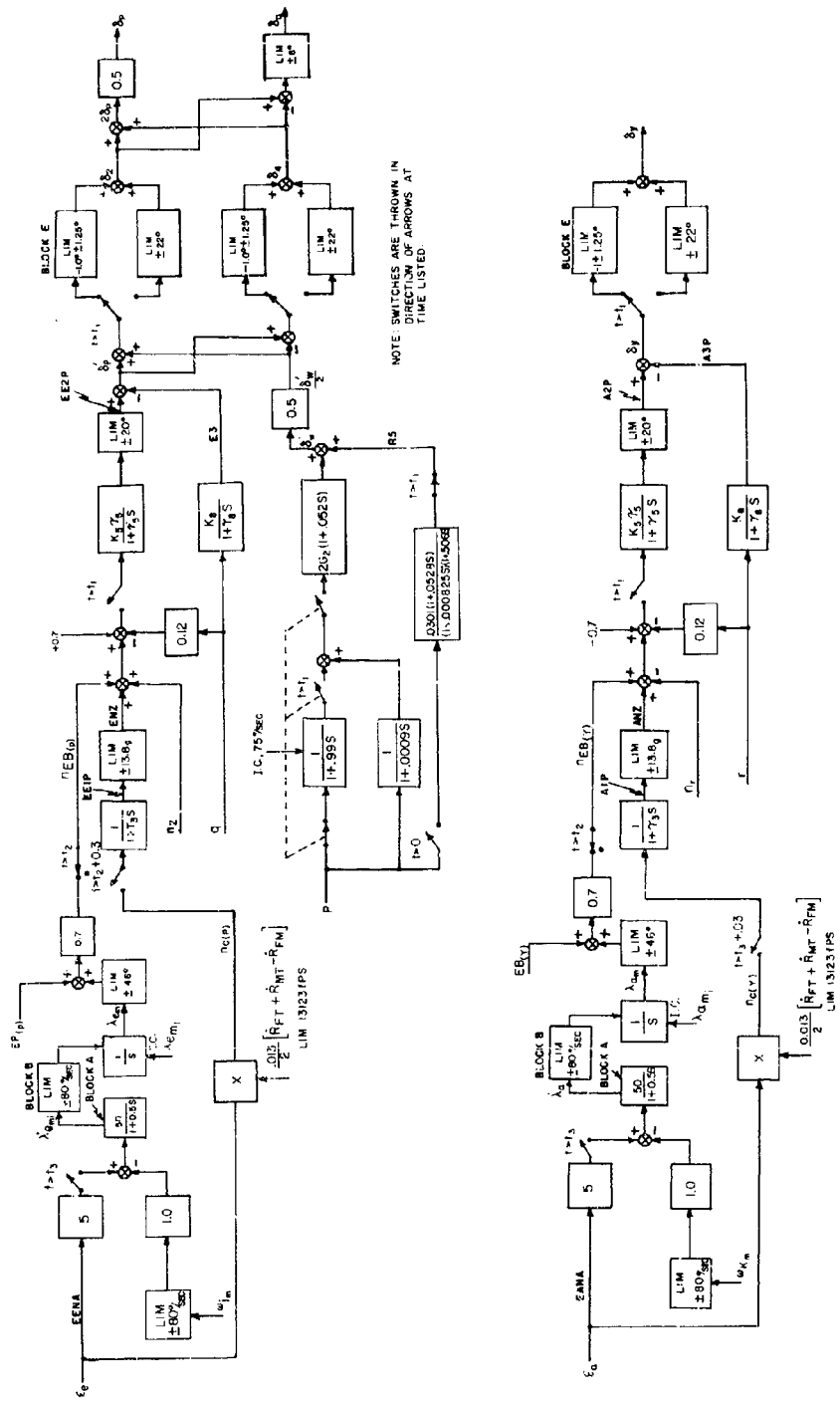
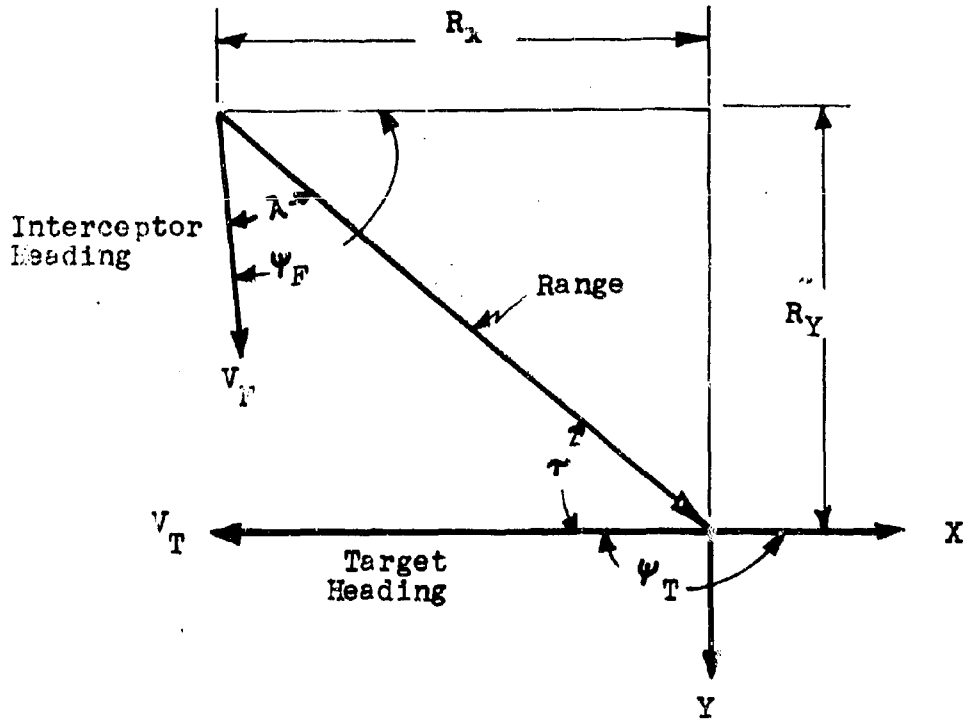


Figure 1 - Sparrow III Autopilot and Seeker Block Diagram



R = Range Vector
X,Y,Z = Reference Axes
R_X, R_Y, R_Z = Components of Range Along X,Y,Z (Z-Axis Positive Downward)
τ = Angle off the Target Nose
ψ_F = Eulerian Angle of Fighter Velocity Vector in Azimuth
V_F = Fighter Velocity Vector
V_T = Target Velocity Vector
λ = Lead Angle

Fig. 2 - Attack Geometry

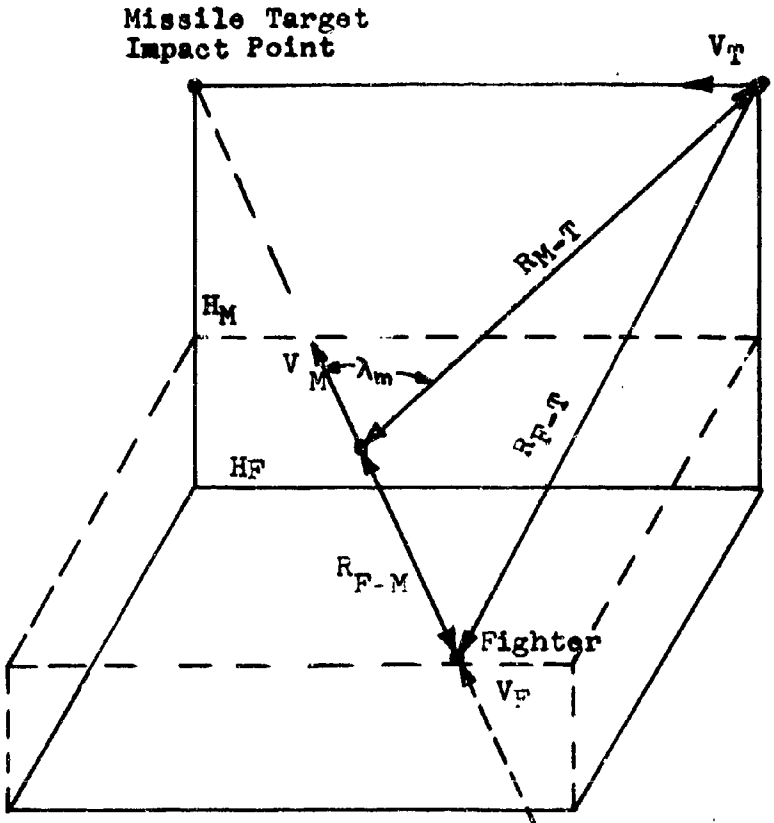


Figure 3-Typical Missile Guidance Geometry

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Fig. 4a- Sparrow III Miss Distance - Co-altitude Attacks
X-Y Miss Distance at the Target
$\gamma_o = 15°$, R_{Max} Launch, Fighter Course - 6-3
Unimproved Missile

$\frac{V_F}{V_T} = 1.0$

$V_T = M\ 2.0$

$H_F = 50{,}000$ Ft

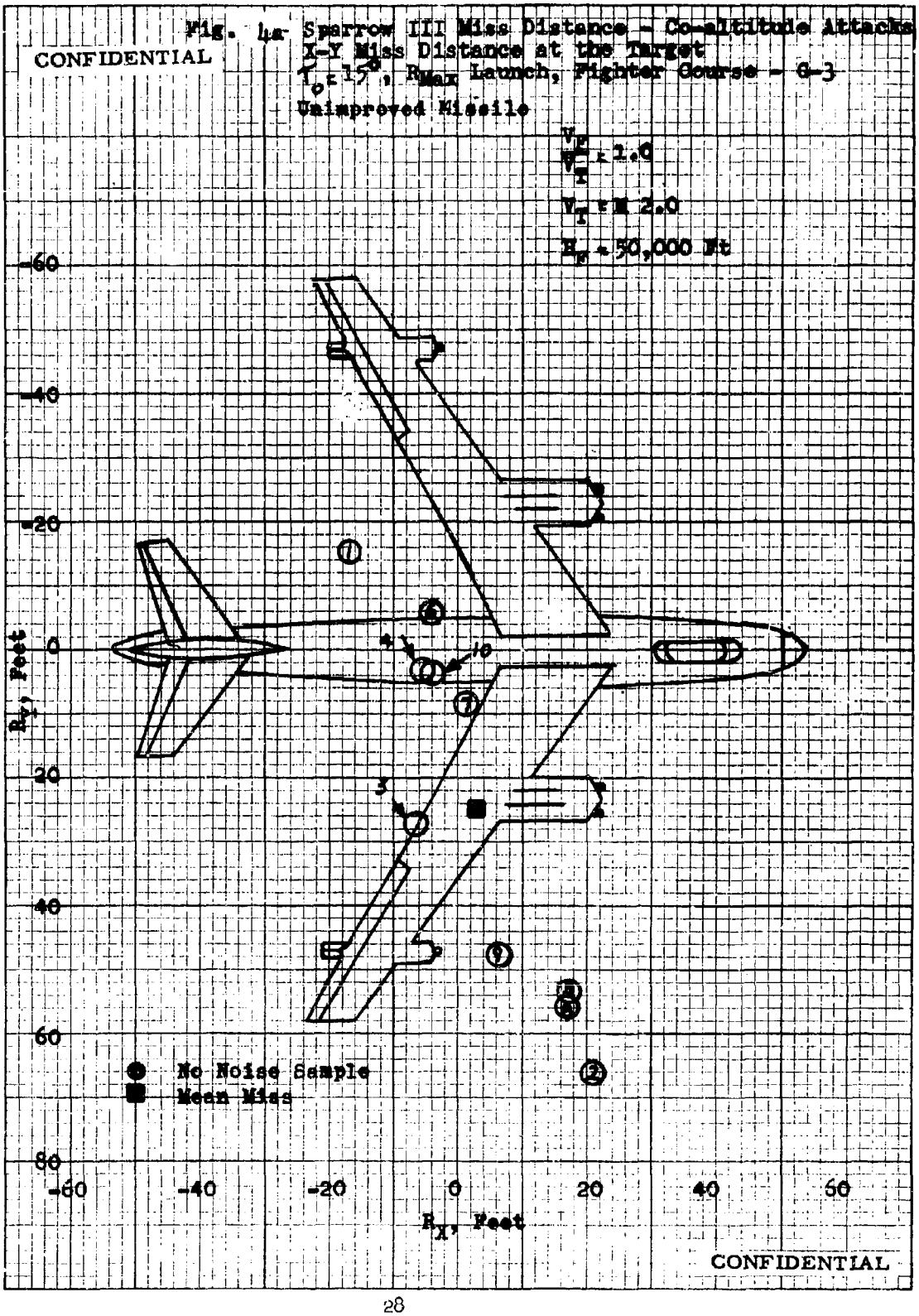

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Fig. 4b Sparrow III Miss Distance - Co-altitude Attacks
X-Z Miss Distance at the Target
γ_o = 15°, R_{max} Launch, Fighter Course = G-3
Unimproved Missile

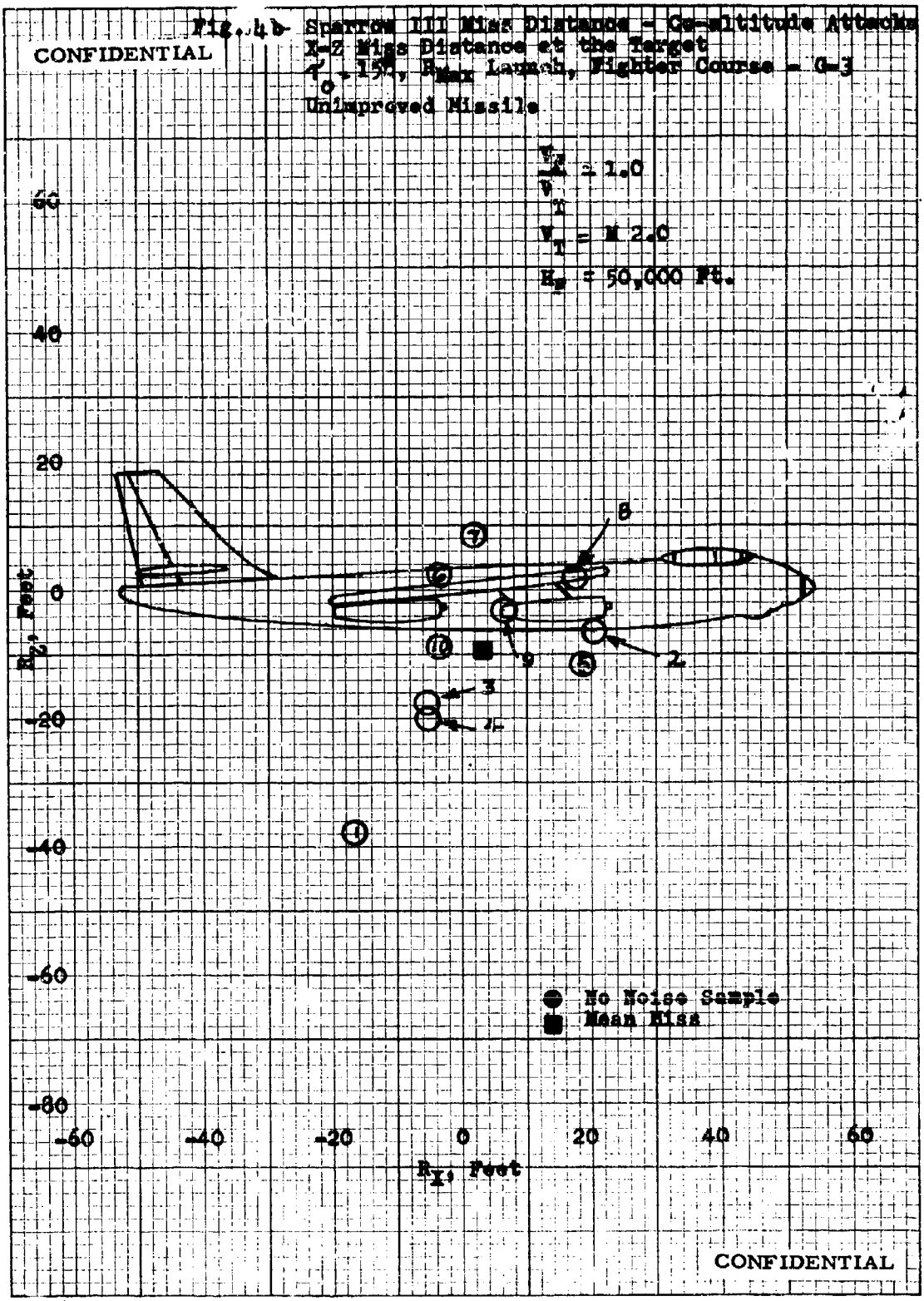

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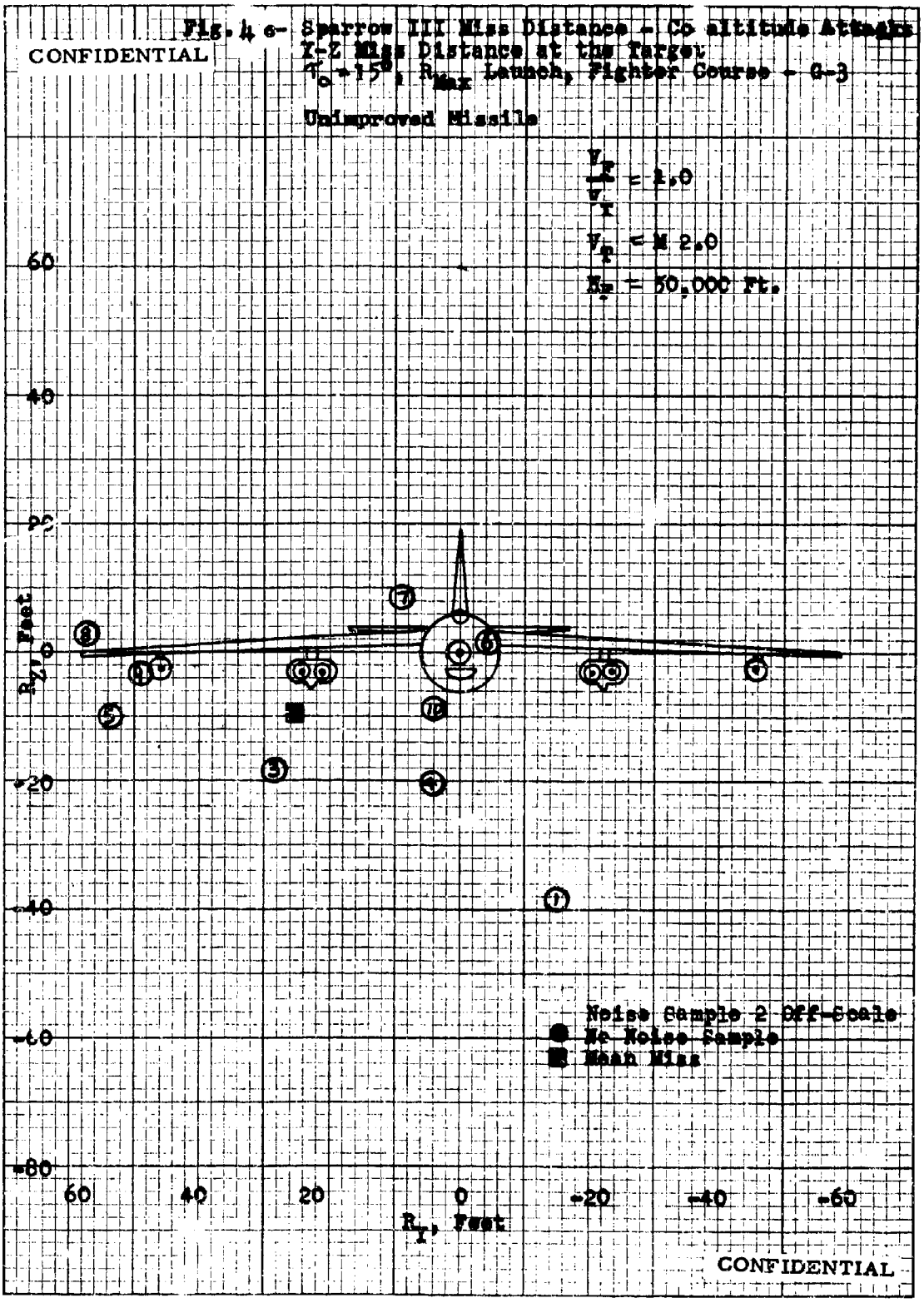
Fig. 4 c- Sparrow III Miss Distance - Co altitude Attacks
X-Z Miss Distance at the Target
$\psi_o = 15°$, R_{Max} Launch, Fighter Course - C-3
Unimproved Missile

$\frac{V_T}{V_I} = 1.0$

$V_T = M\ 2.0$

$X_m = 50,000$ Ft.



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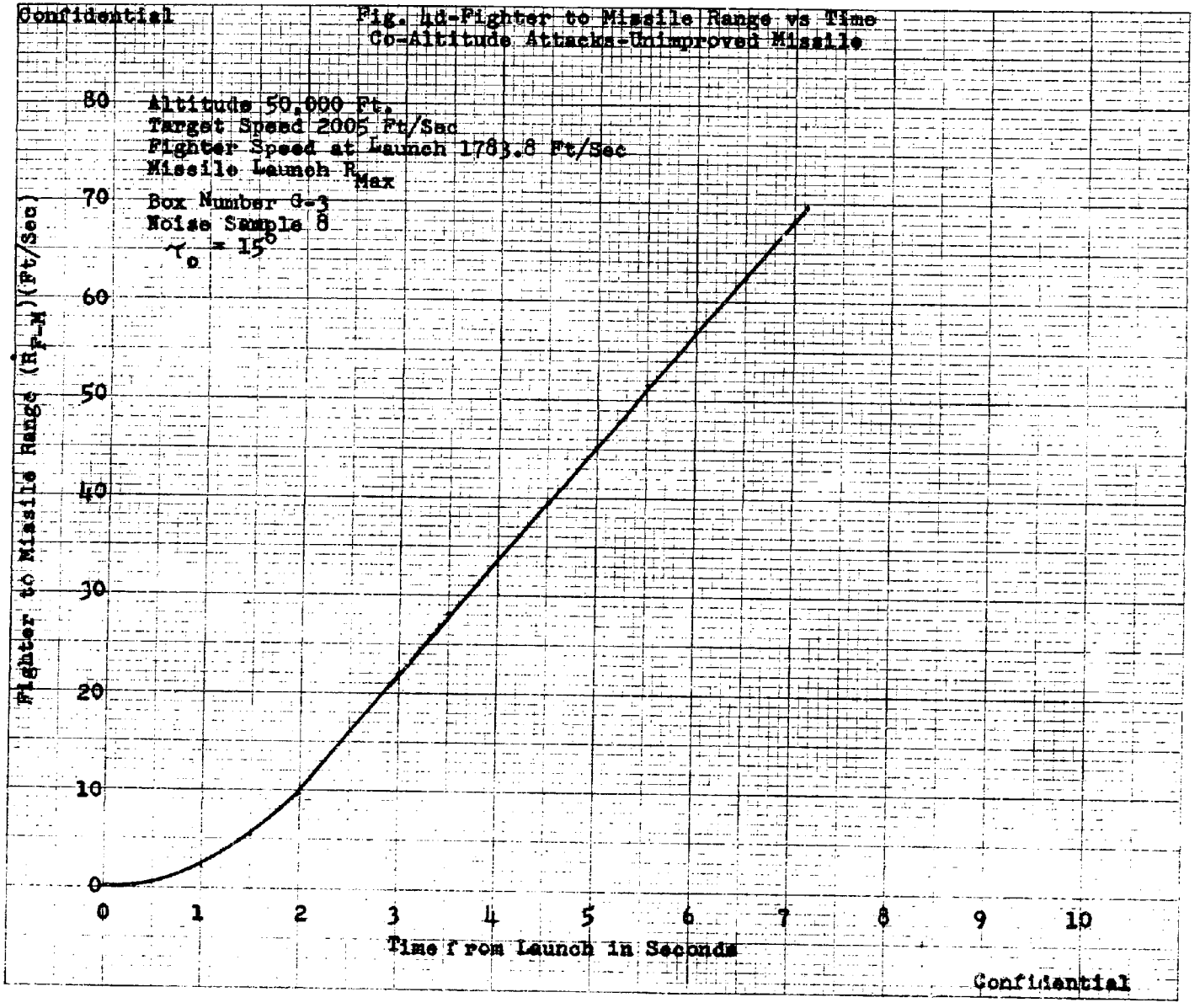
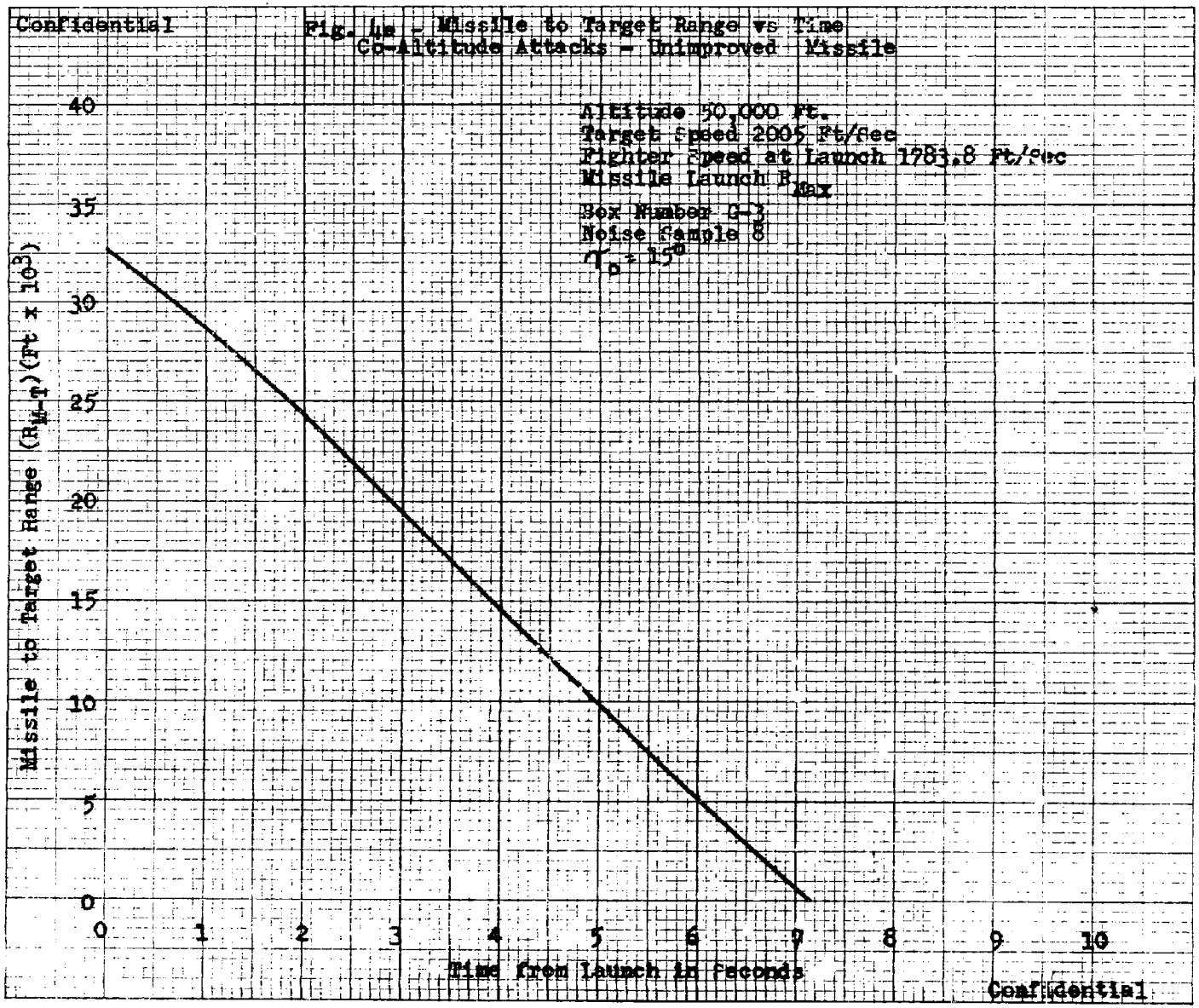


Fig. 4a - Missile to Target Range vs Time
Co-Altitude Attacks - Unimproved Missile



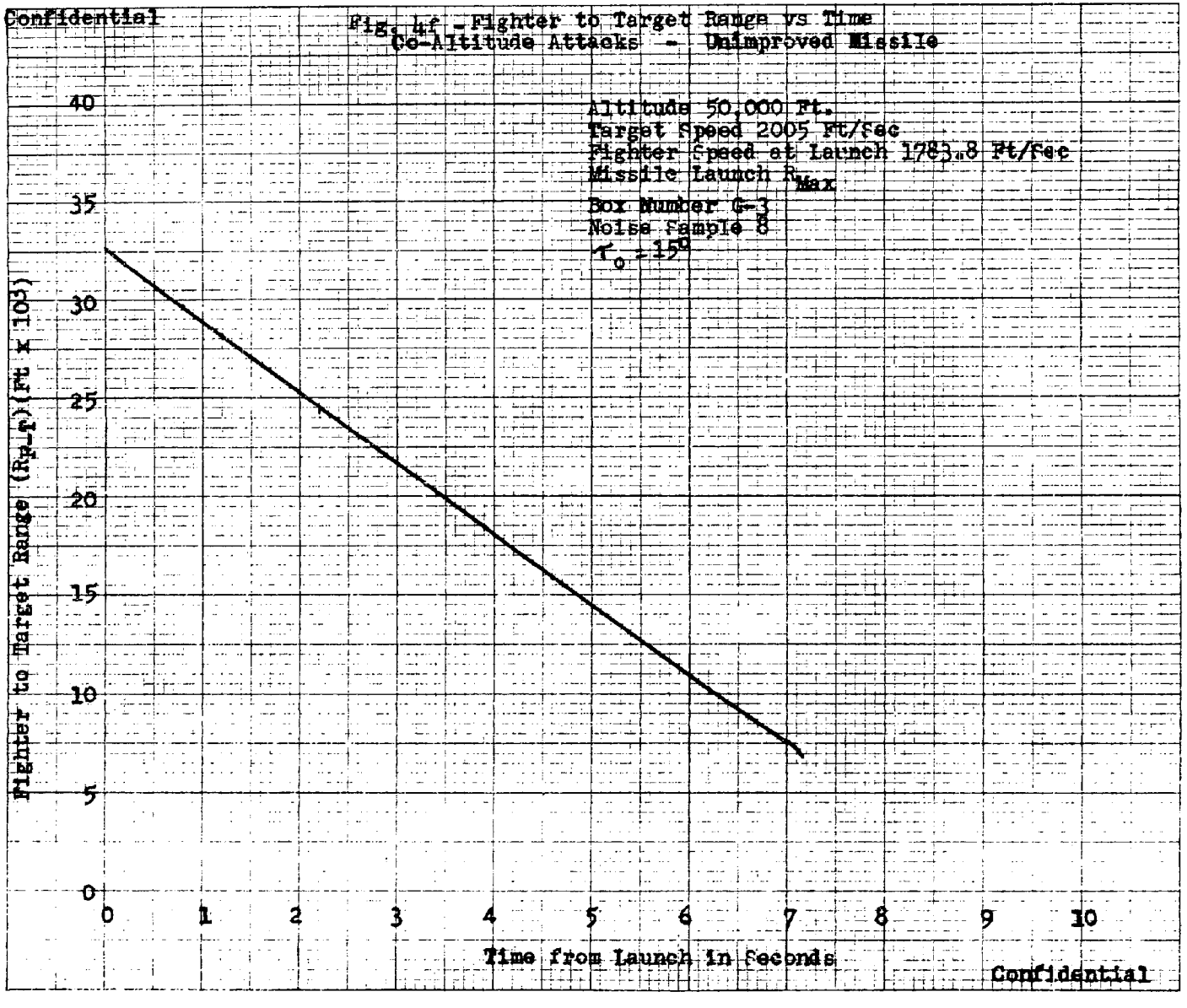
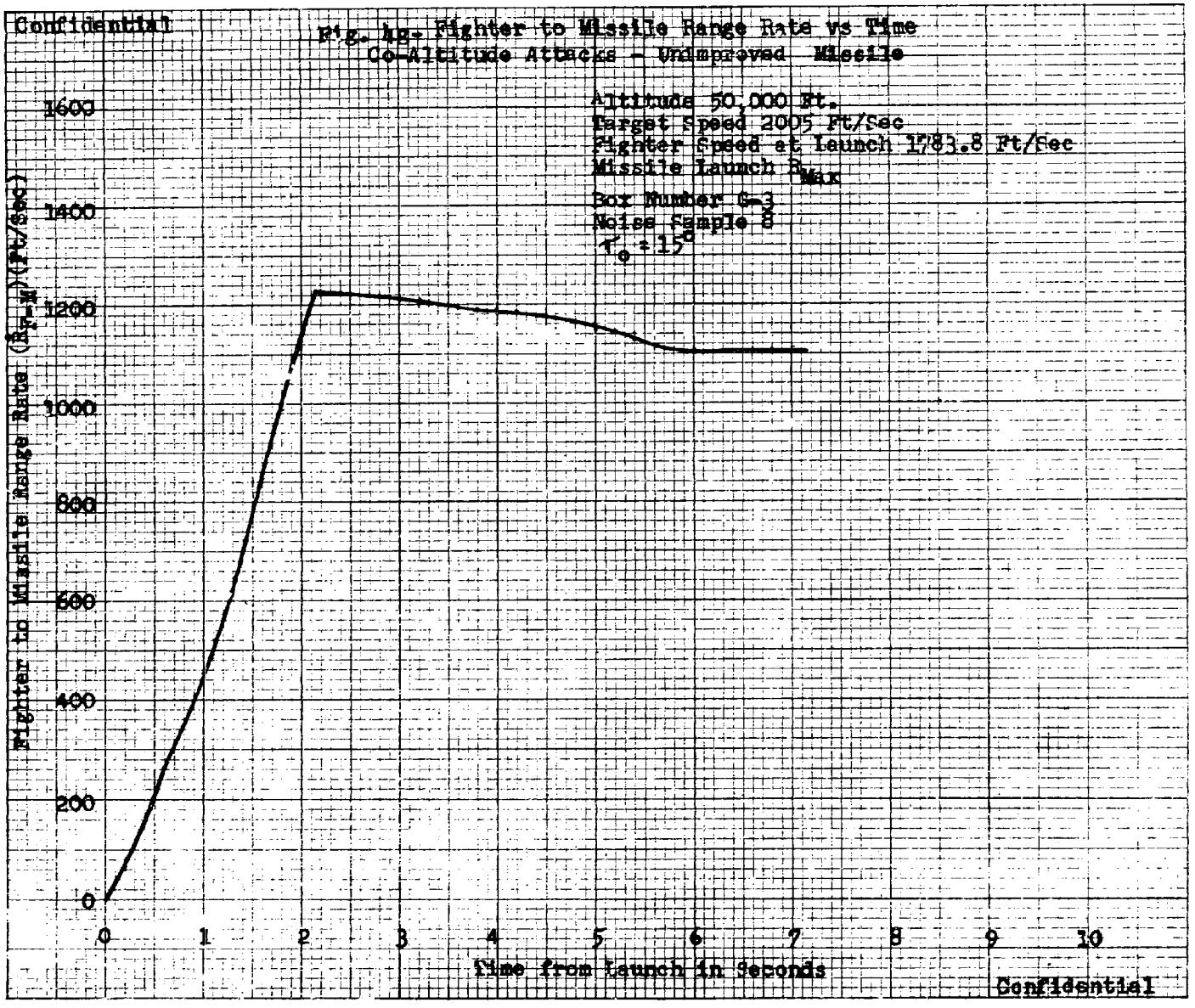
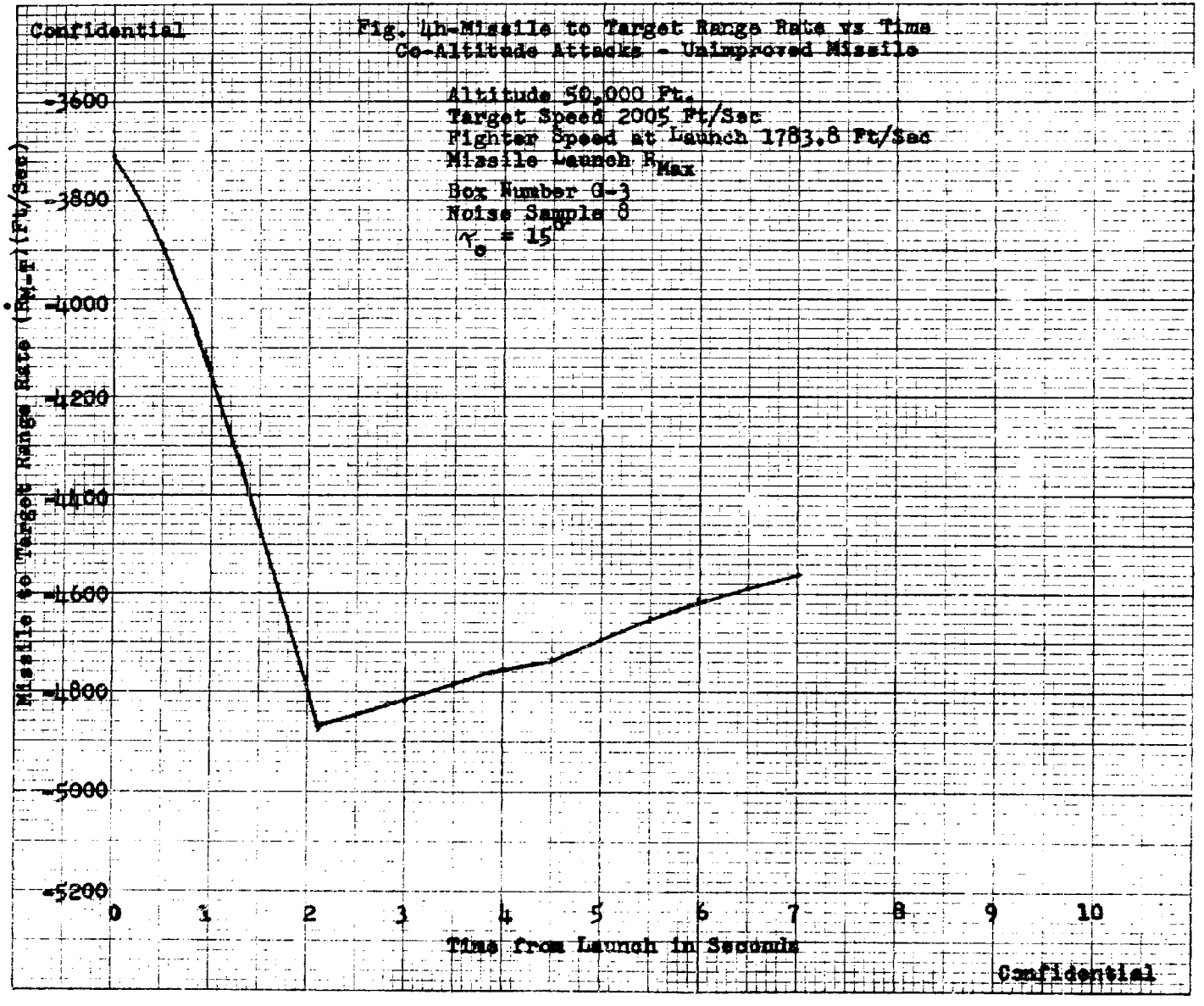


Fig. 4g- Fighter to Missile Range Rate vs Time
Co-Altitude Attacks - Unimproved Missile





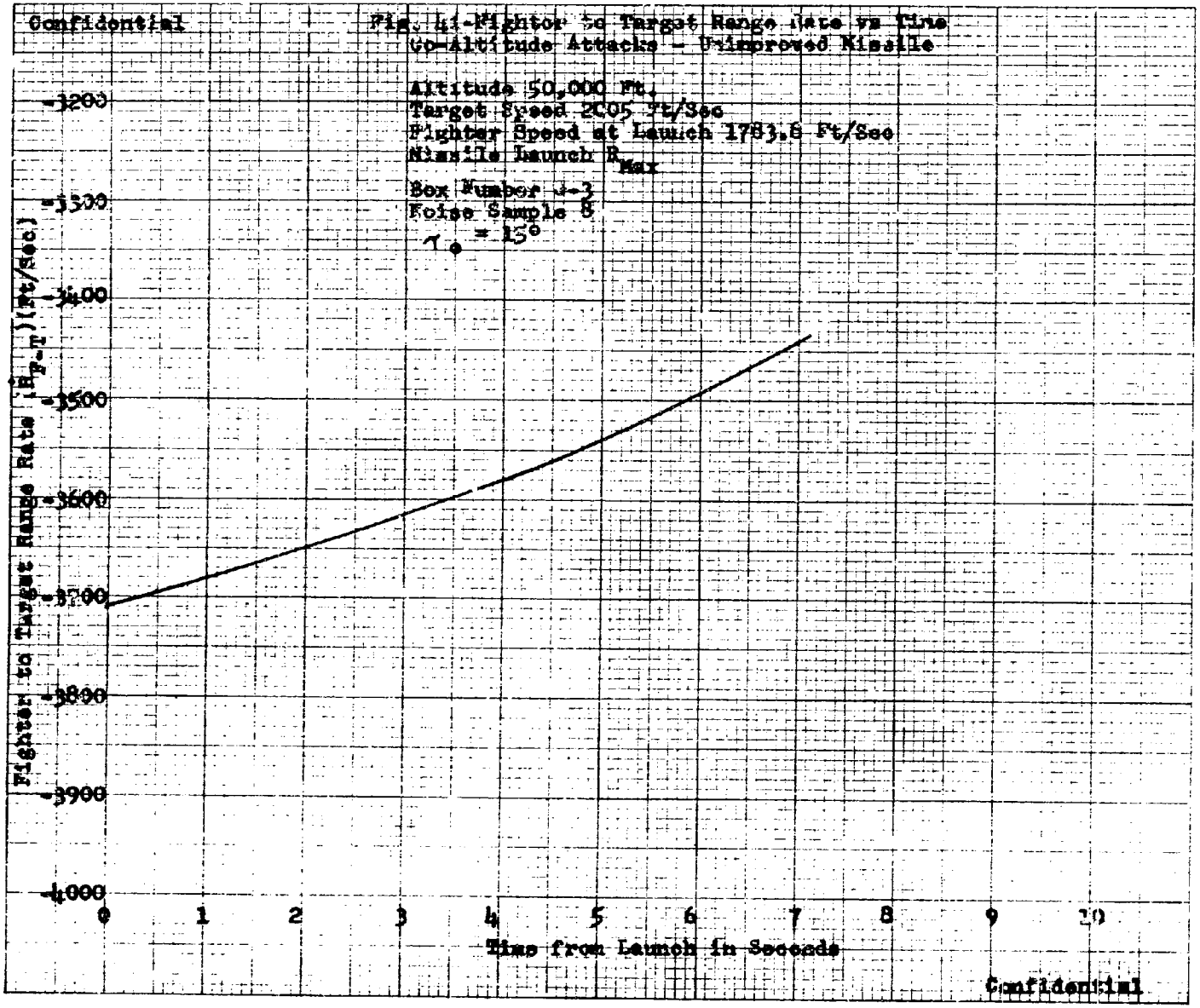

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Fig. 41-Fighter to Target Range Rate vs Time
Co-Altitude Attacks - Unimproved Missile
Altitude 50,000 Ft.
Target Speed 2005 Ft/Sec
Fighter Speed at Launch 1783.6 Ft/Sec
Missile Launch R Max
Box Number 4-3
Noise Sample 8
γ_o = 15°
Fighter to Target Range Rate $(\dot{R}_{F-T})$ (Ft/Sec)
-3200
-3300
-3400
-3500
-3600
-3700
-3800
-3900
-4000
0
1
2
3
4
5
6
7
8
9
10
Time from Launch in Seconds
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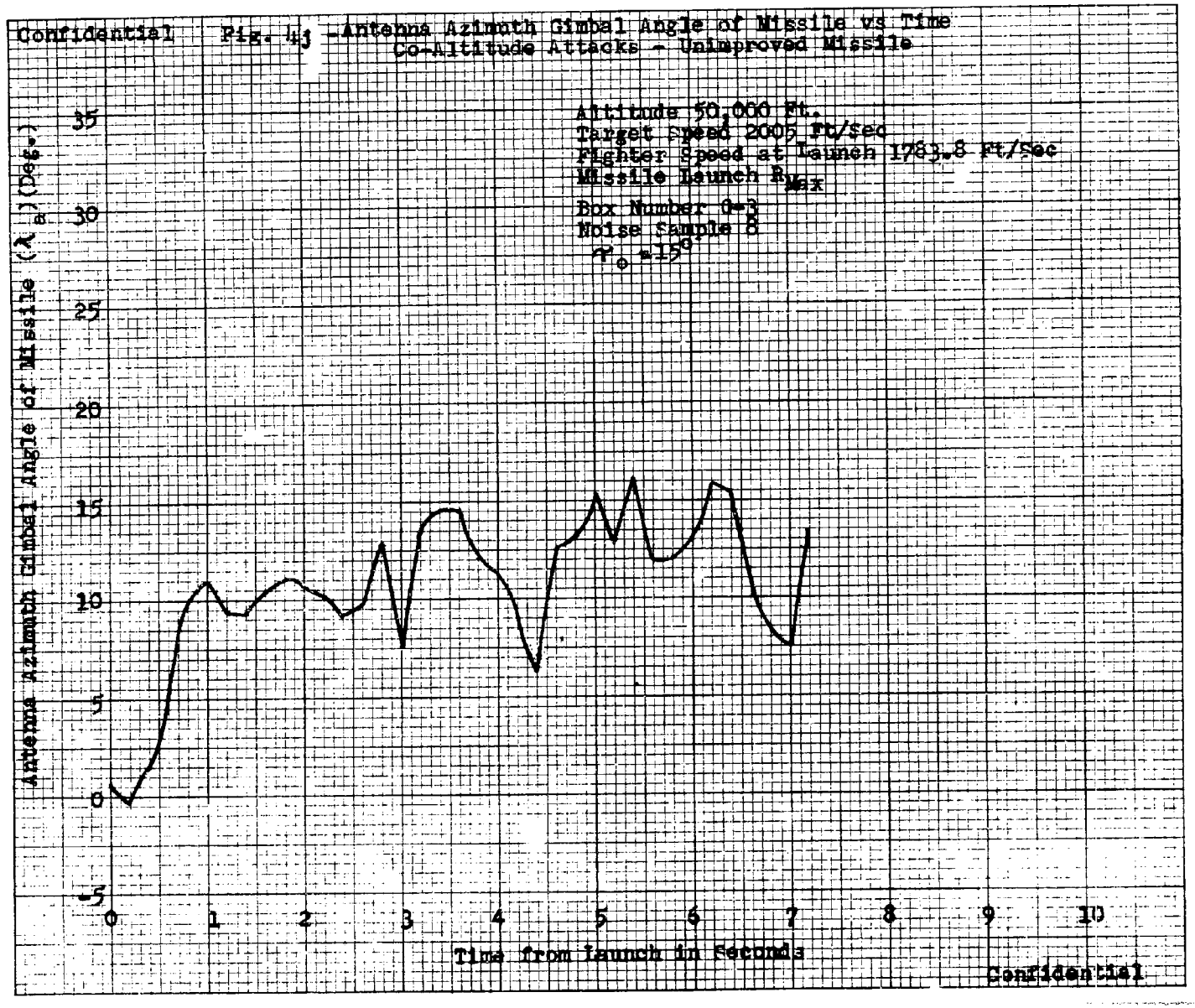

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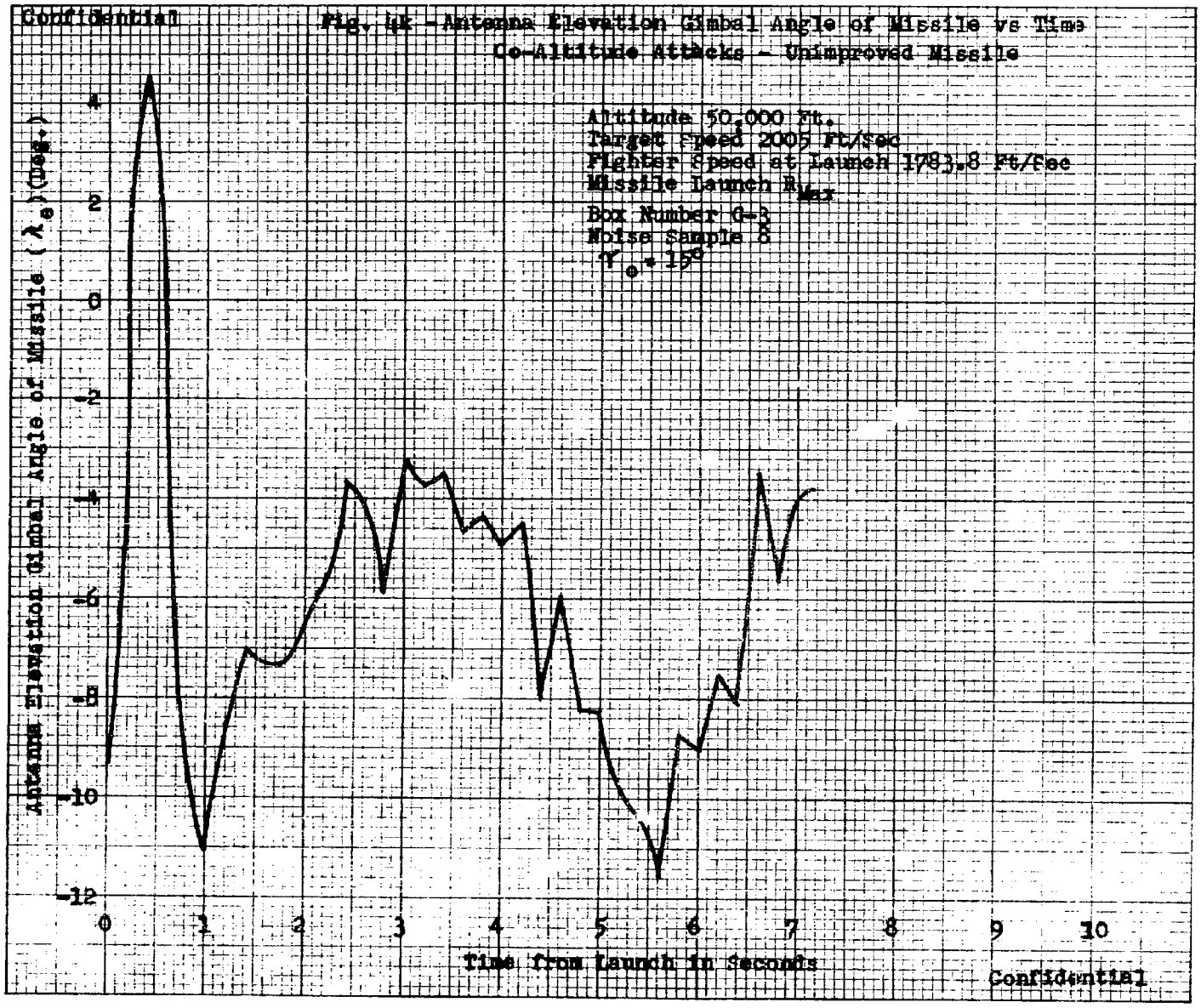
Fig. 4k - Antenna Elevation Gimbal Angle of Missile vs Time
Co-Altitude Attacks - Unimproved Missile



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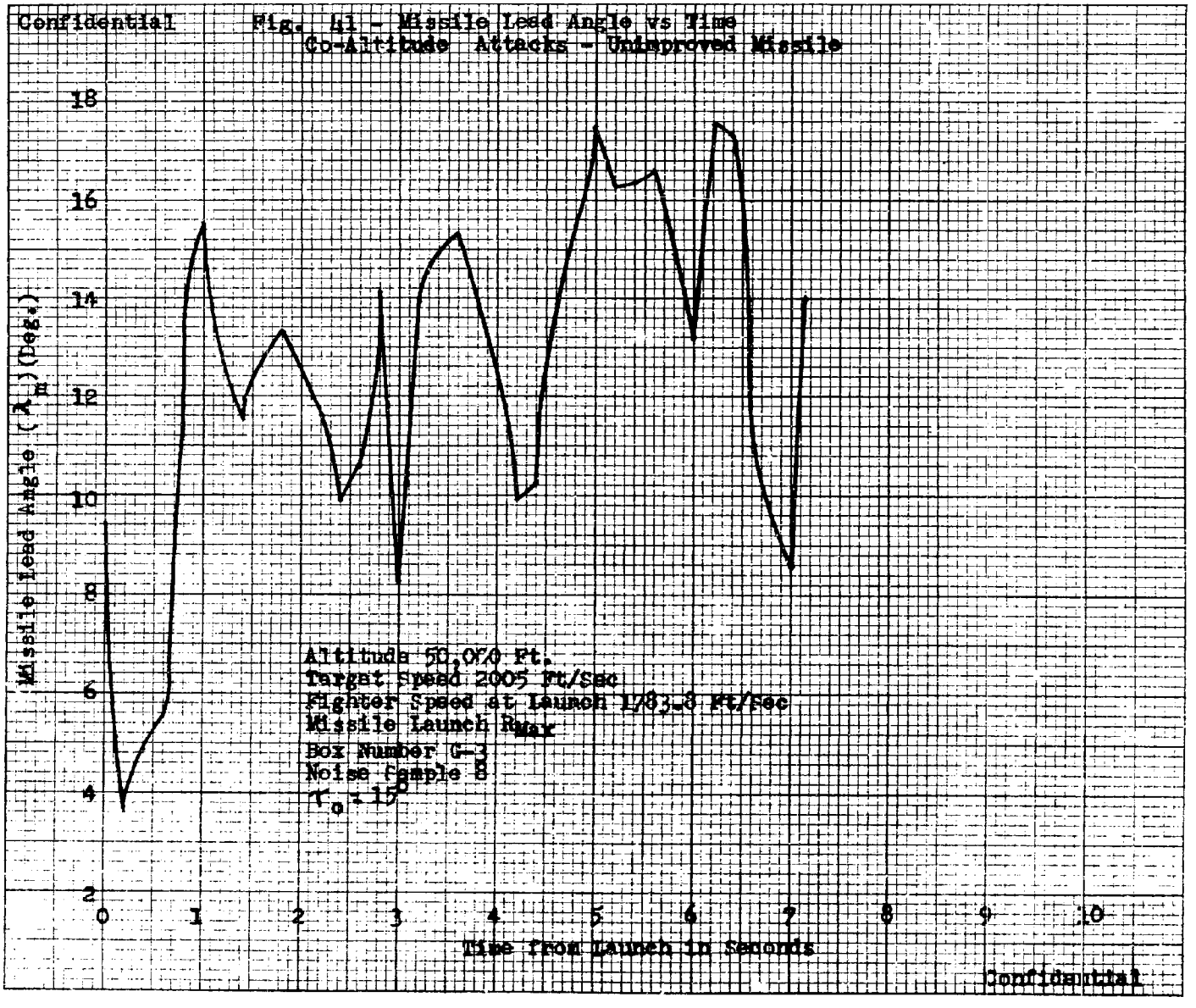

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Fig. 4m - Azimuth Line of Sight Rate of Missile vs Time
Co-Altitude Attacks - Unimproved Missile

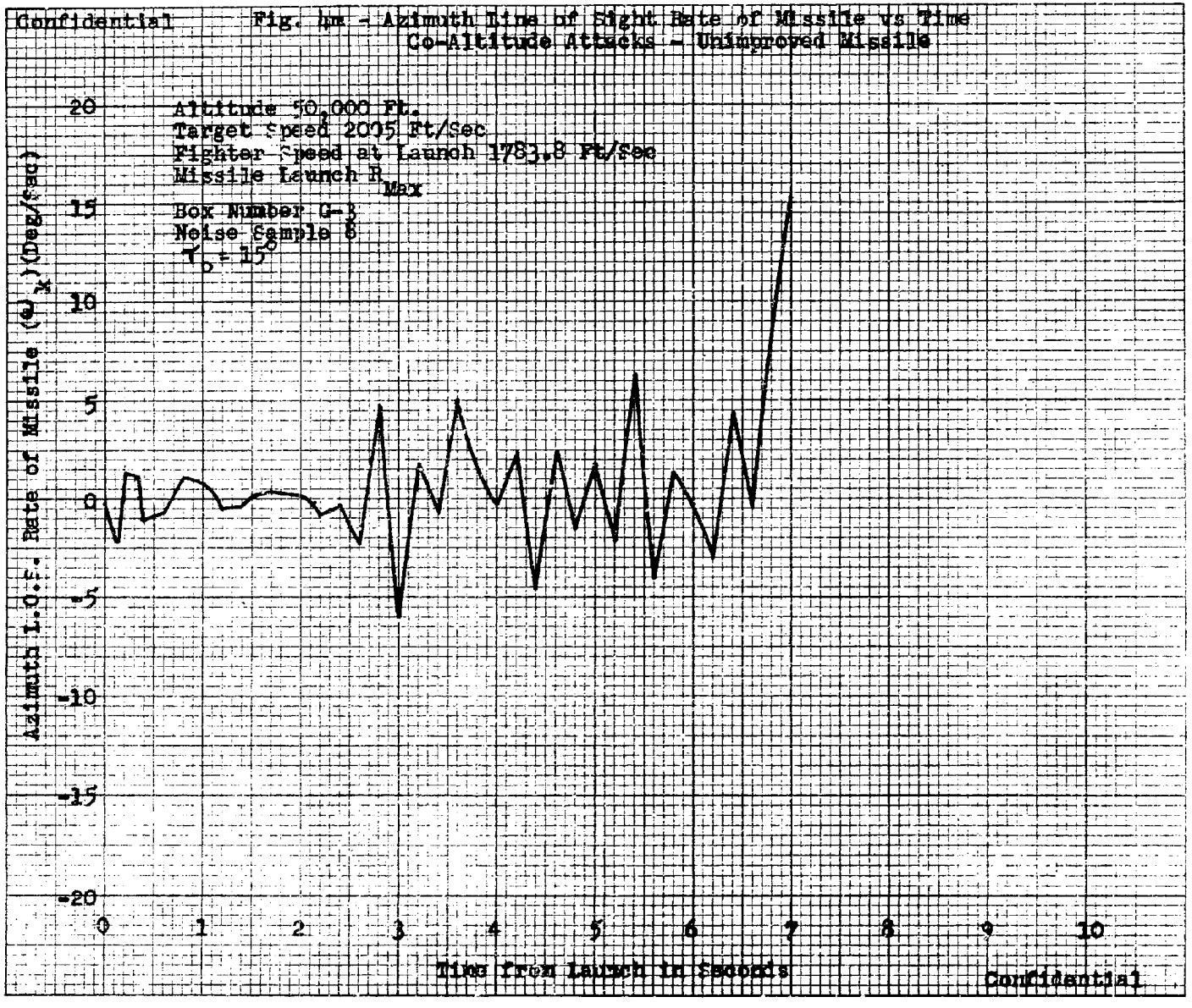

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Fig. 4n - Elevation Line of Sight Rate of Missile vs Time
Co-Altitude Attacks - Unimproved Missile

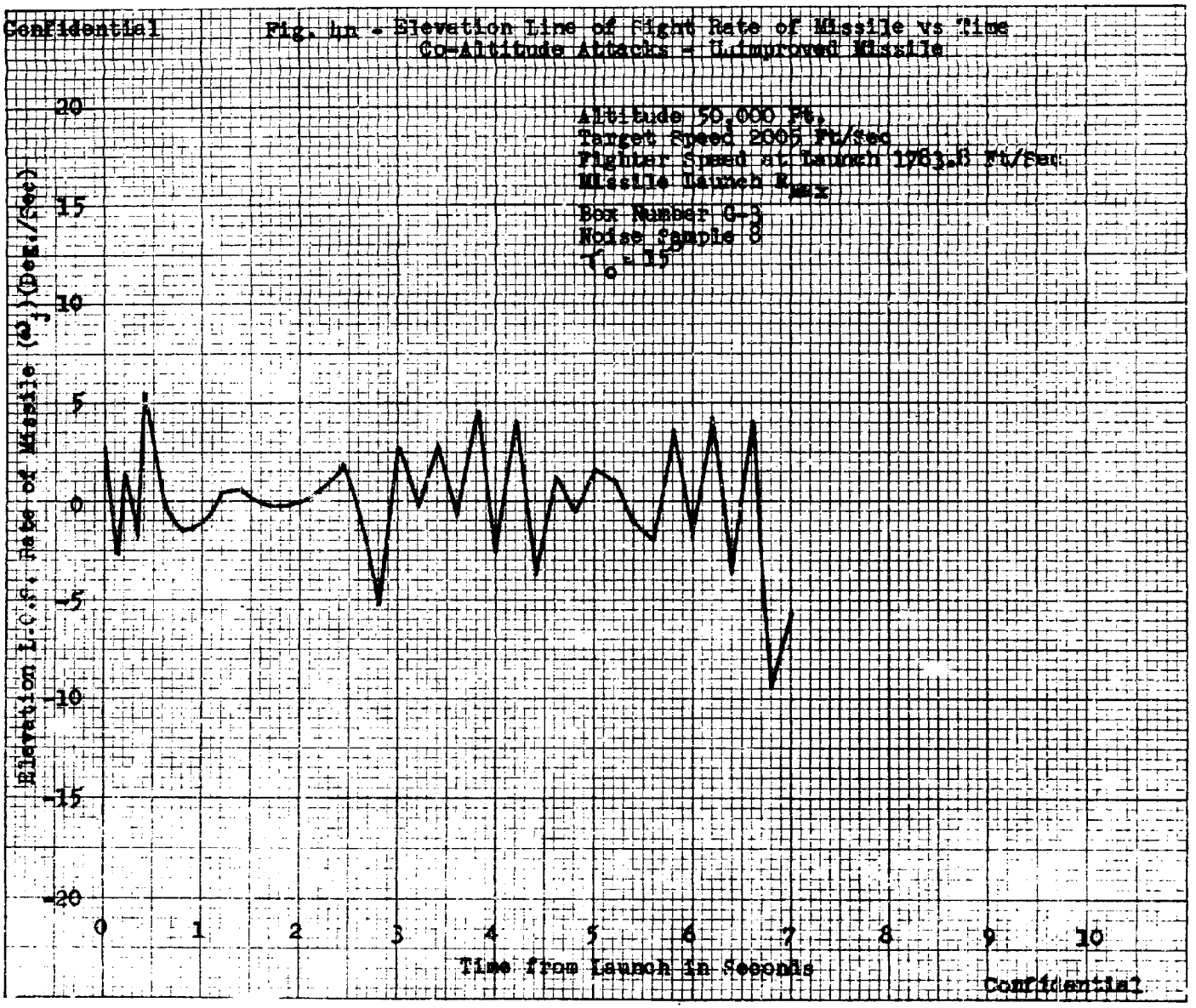
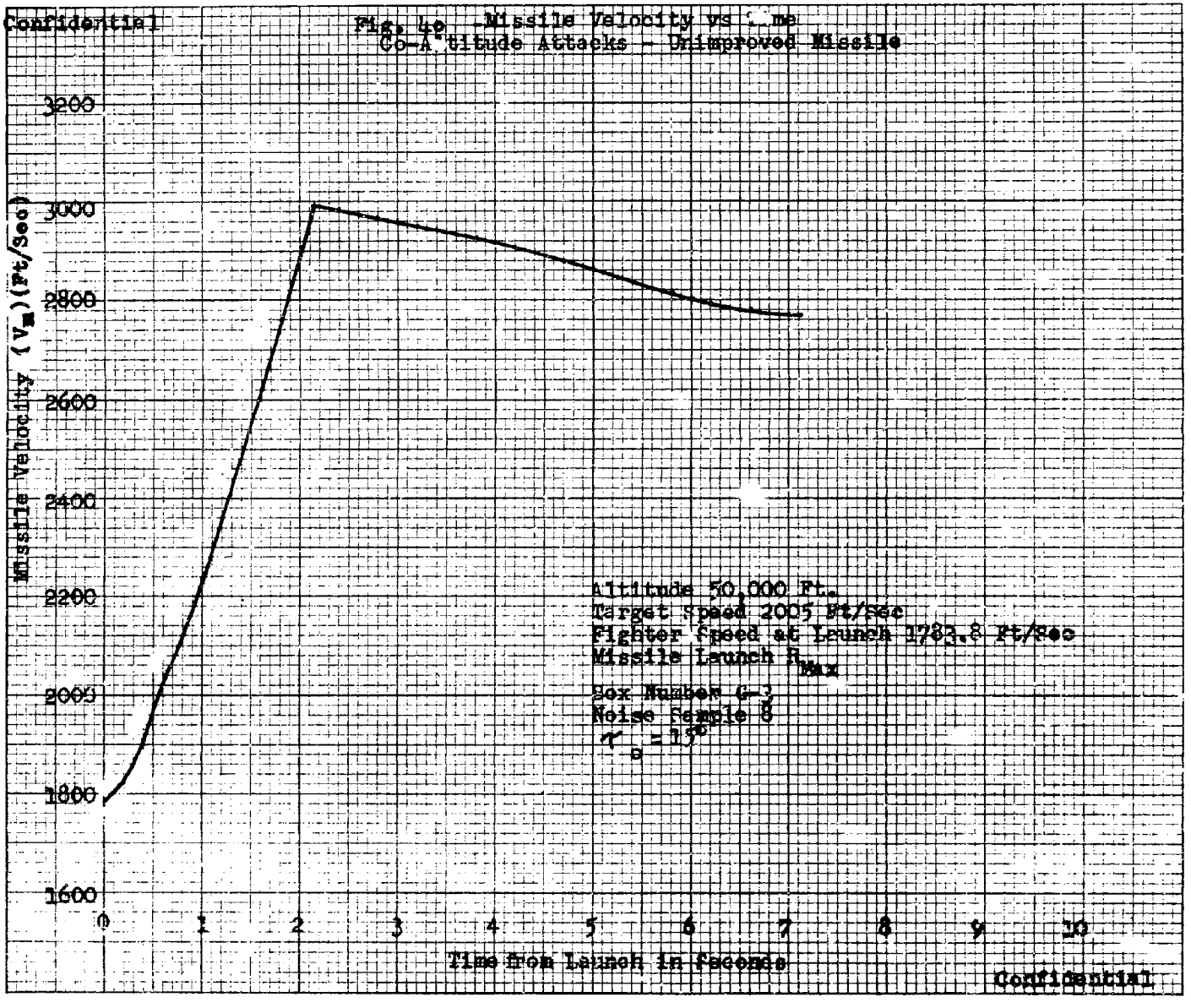


Fig. 40 Missile Velocity vs Time
Co-Altitude Attacks - Unimproved Missile



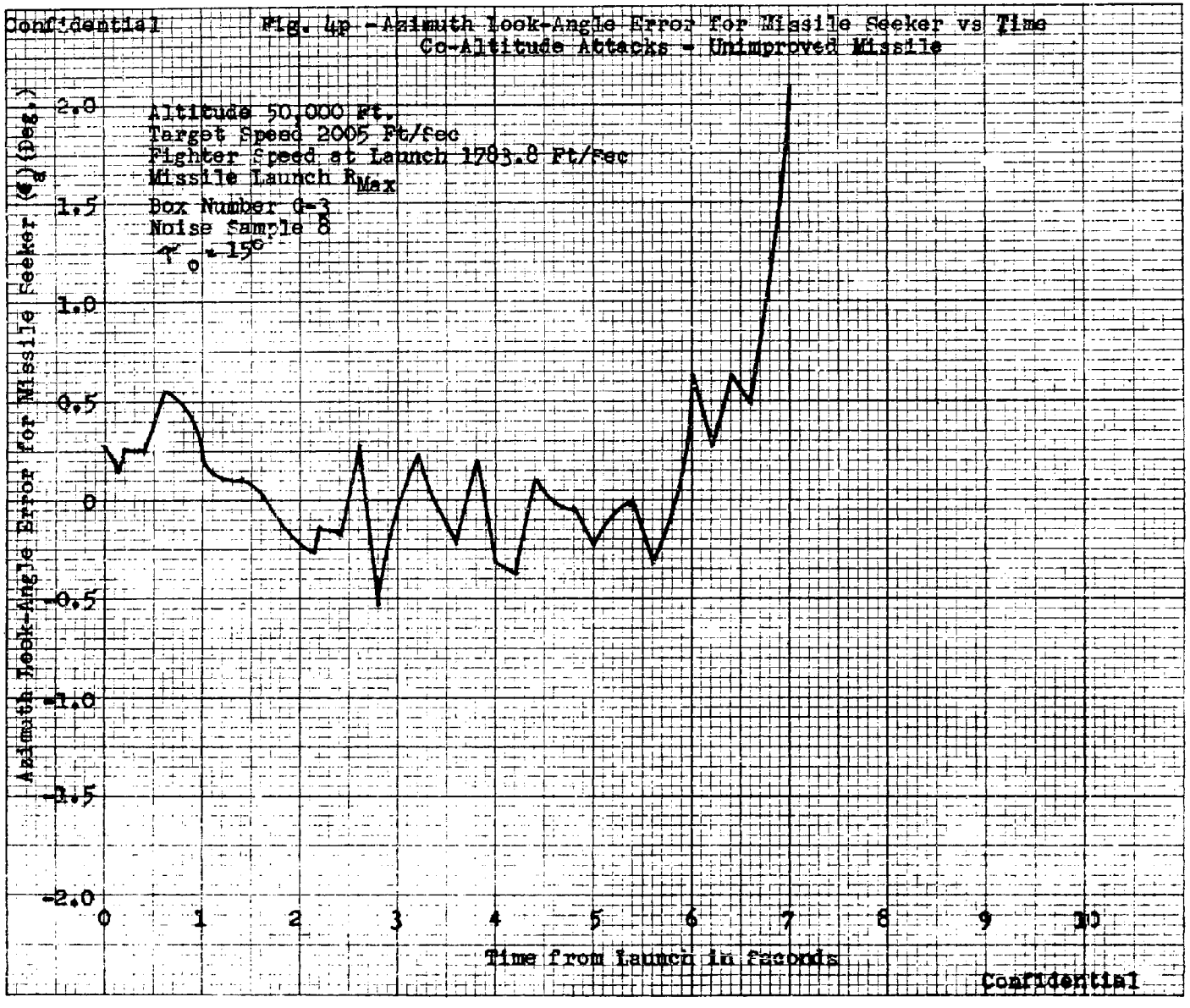


Fig. 44 - Elevation Look-Angle Error for Missile Seeker vs Time
Co-Altitude Attacks - Unimproved Missile

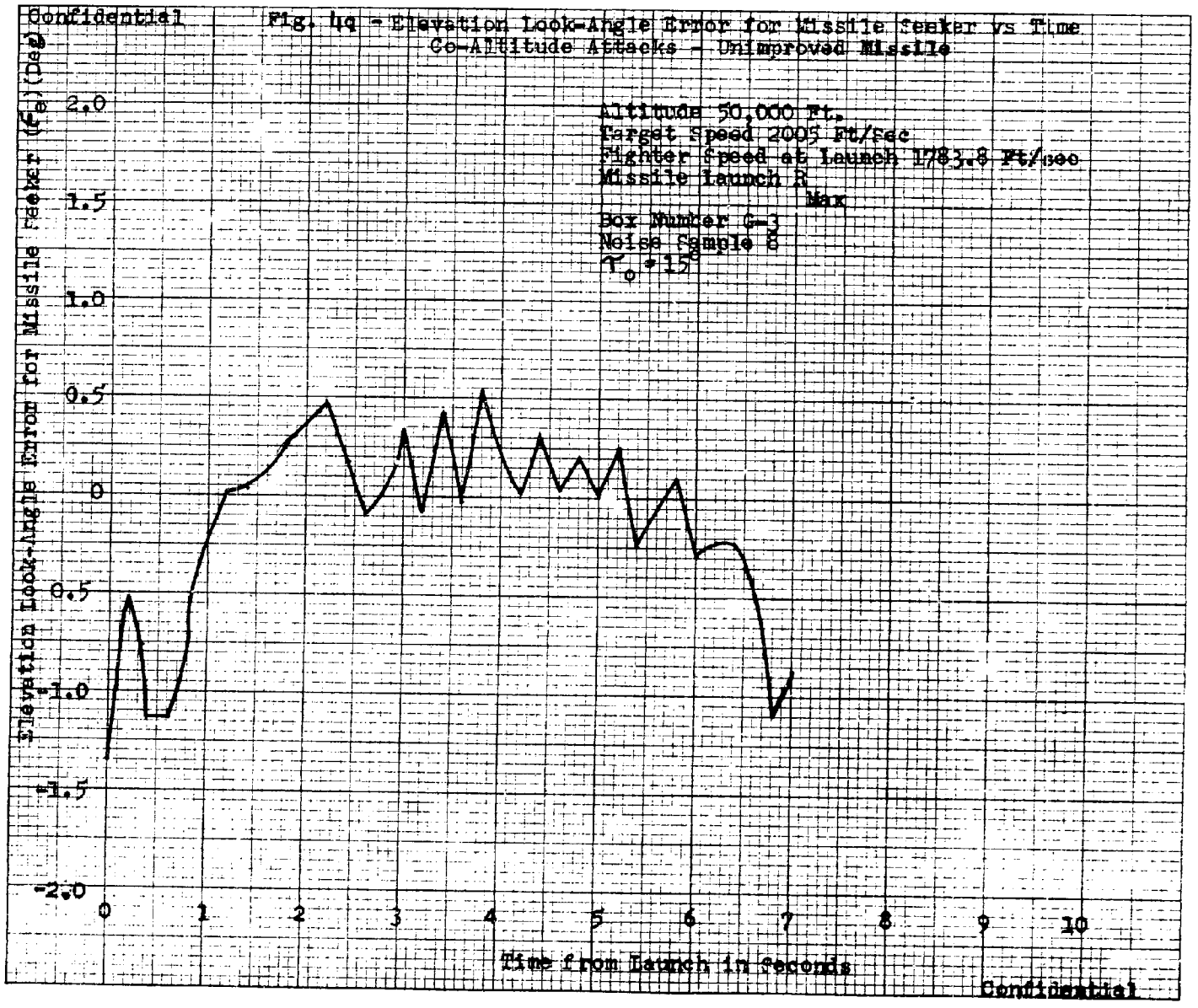


Fig. 4r - Missile Angle of Attack vs Time
Co-Altitude Attacks - Unimproved Missile

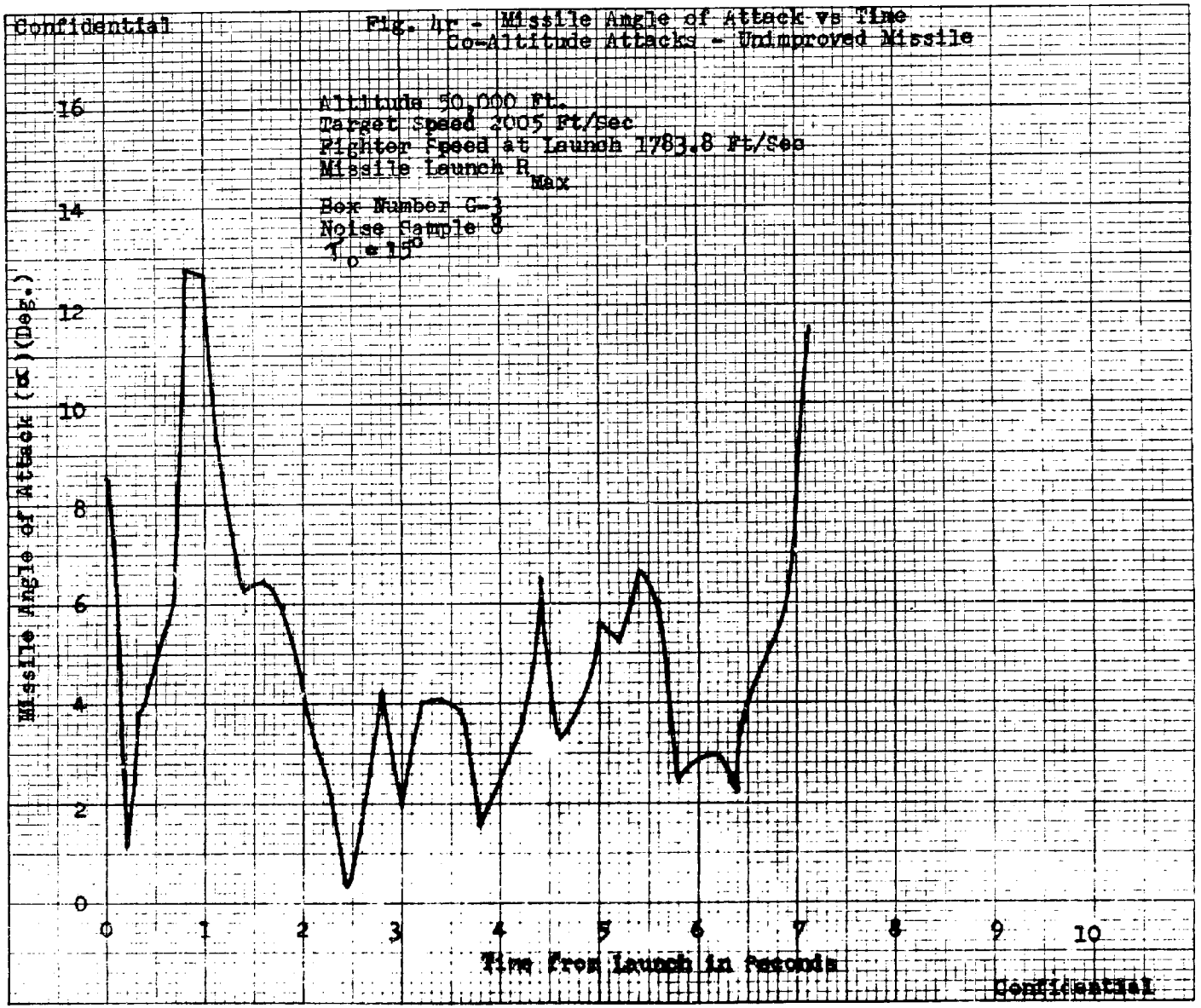


Fig. 44-Missile and Fighter Roll Angles vs Time
Co-Altitude Attacks-Improved Missile

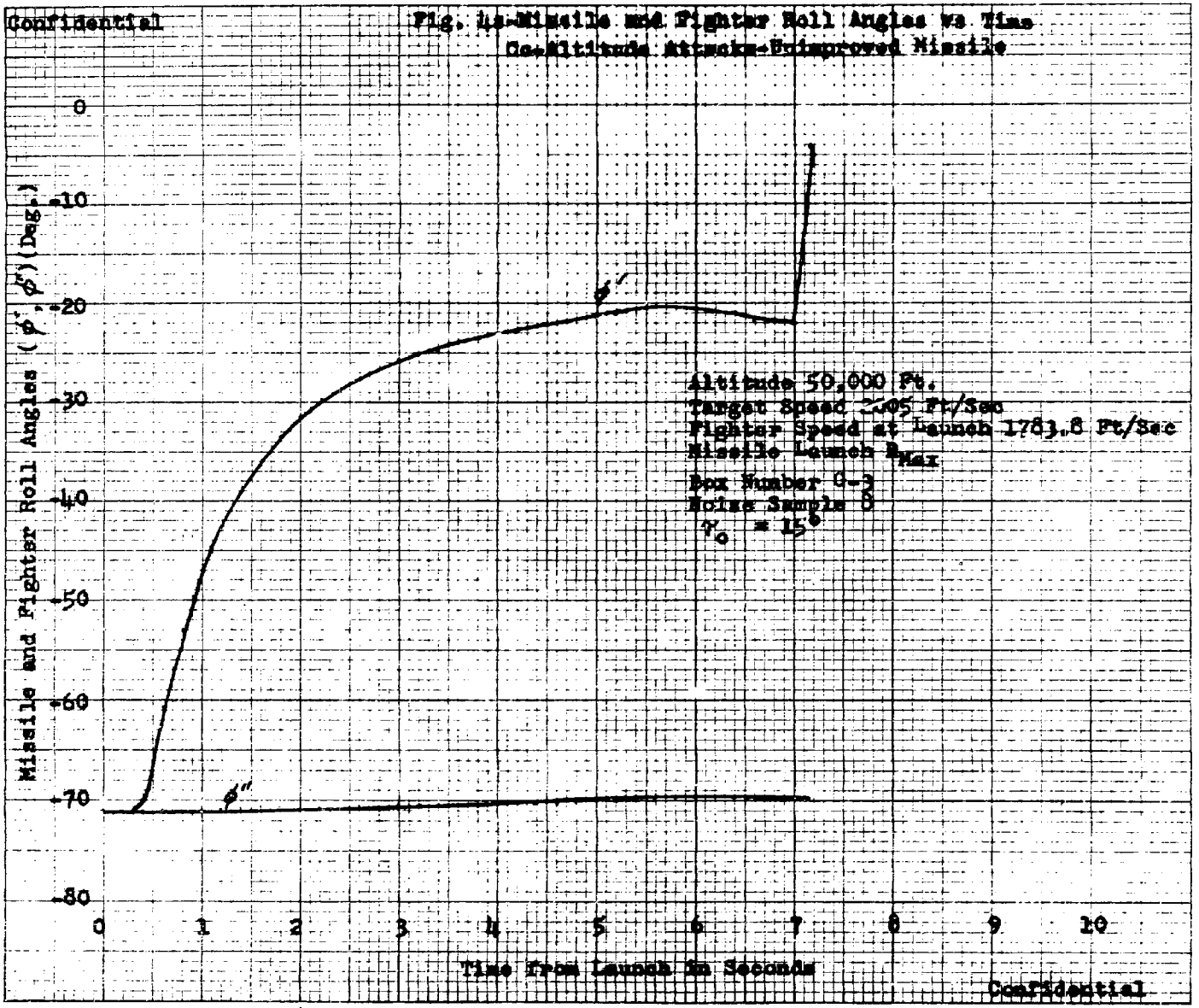
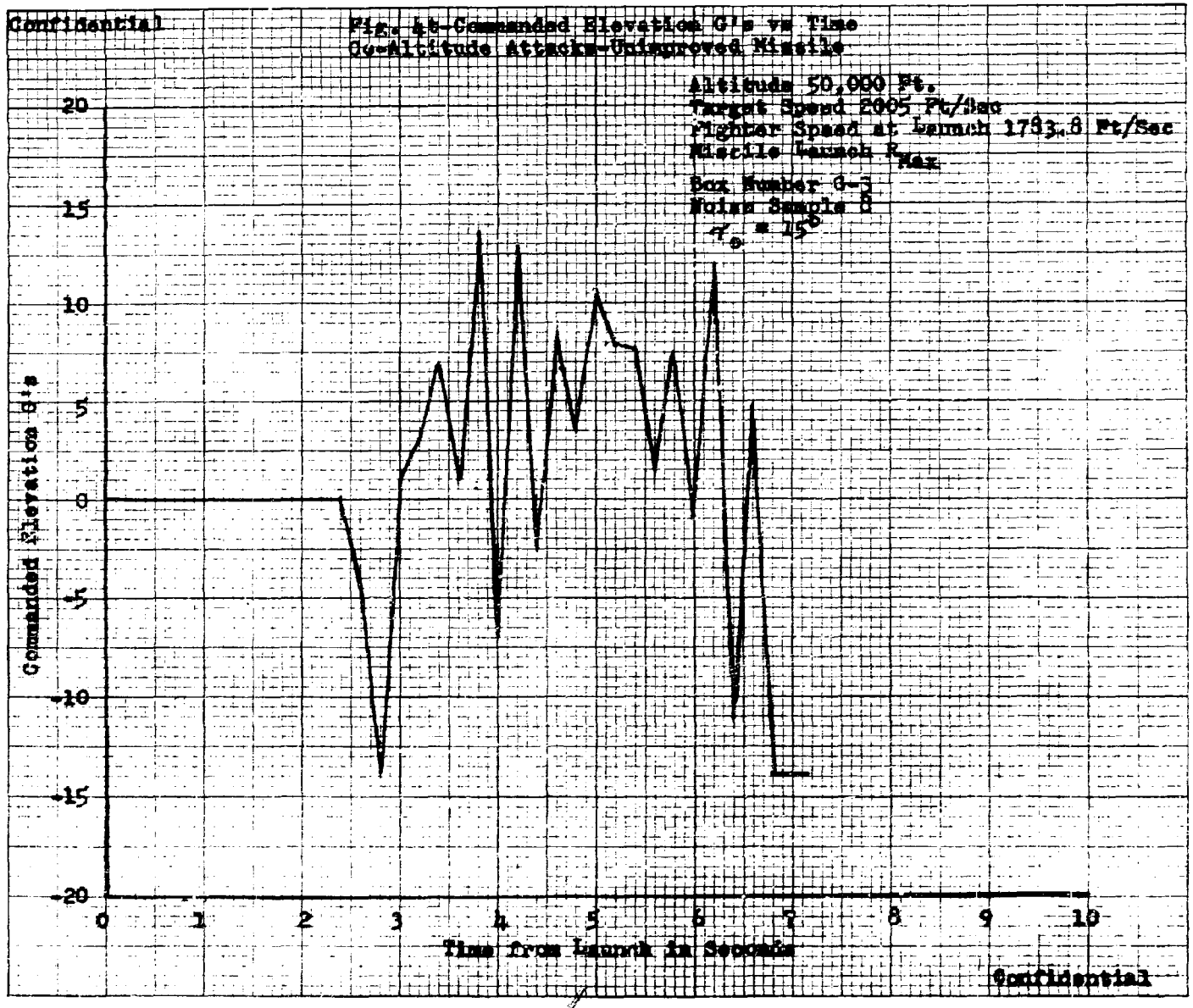


Fig. 46-Commanded Elevation G's vs Time
Co-Altitude Attacks-Unimproved Missile



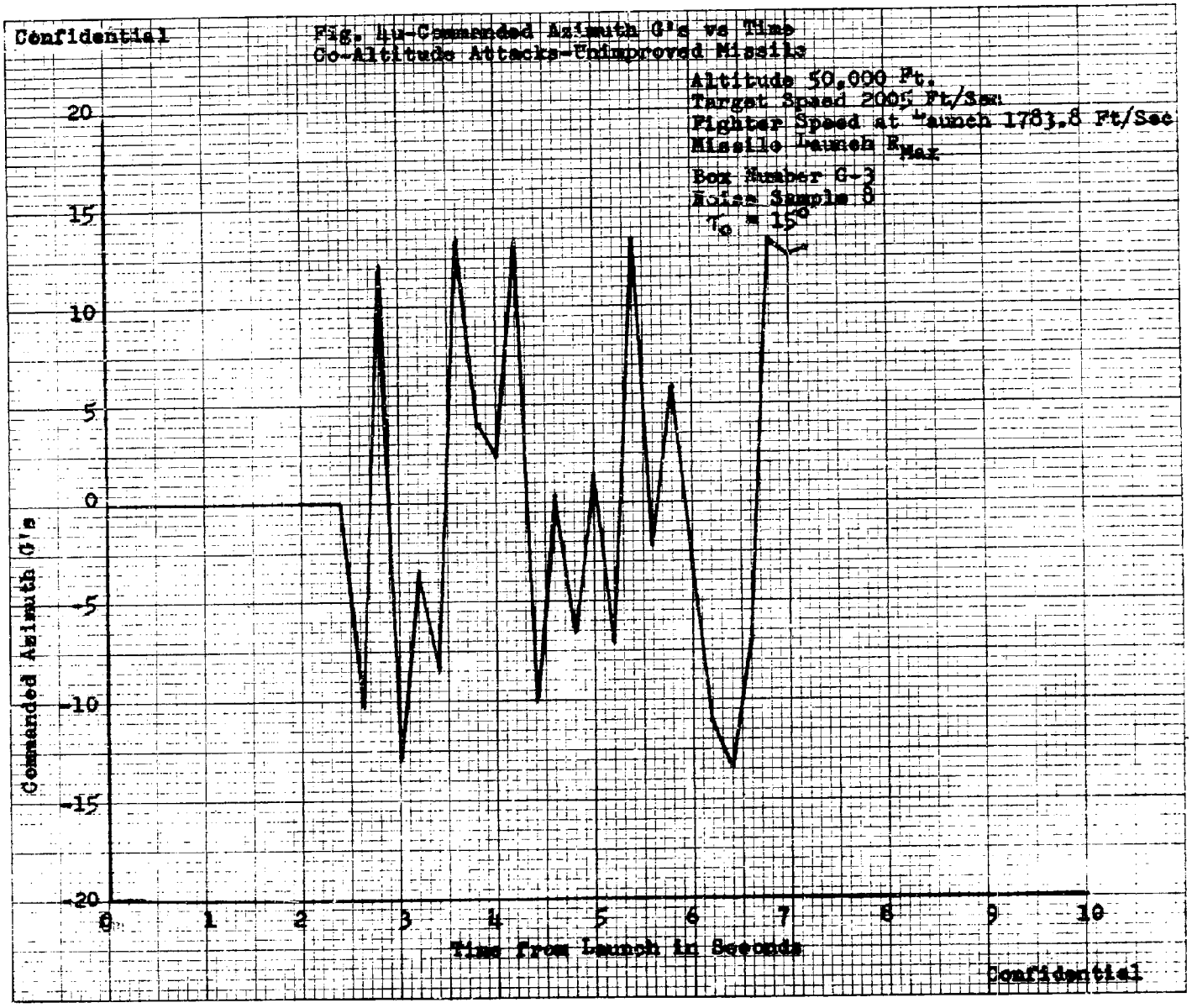


Fig. 44-Commanded Azimuth G's vs Time
Co-Altitude Attacks-Unimproved Missile
Altitude 50,000 Ft.
Target Speed 2005 Ft/Sec
Fighter Speed at Launch 1783.8 Ft/Sec
Missile Launch R Max
Box Number C-3
Noise Sample 8
τ_o = 15°
Commanded Azimuth G's
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
10
Time From Launch in Seconds

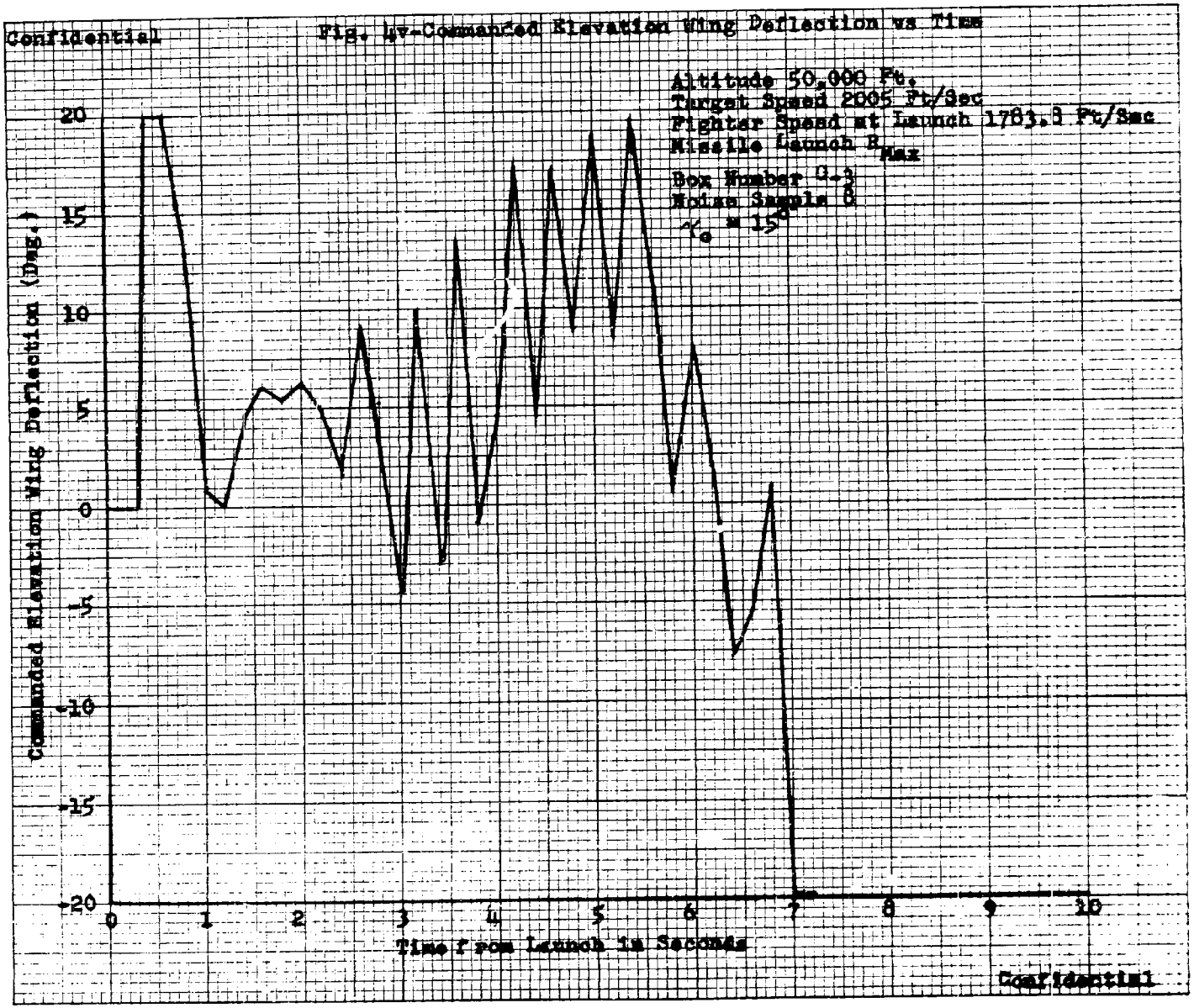
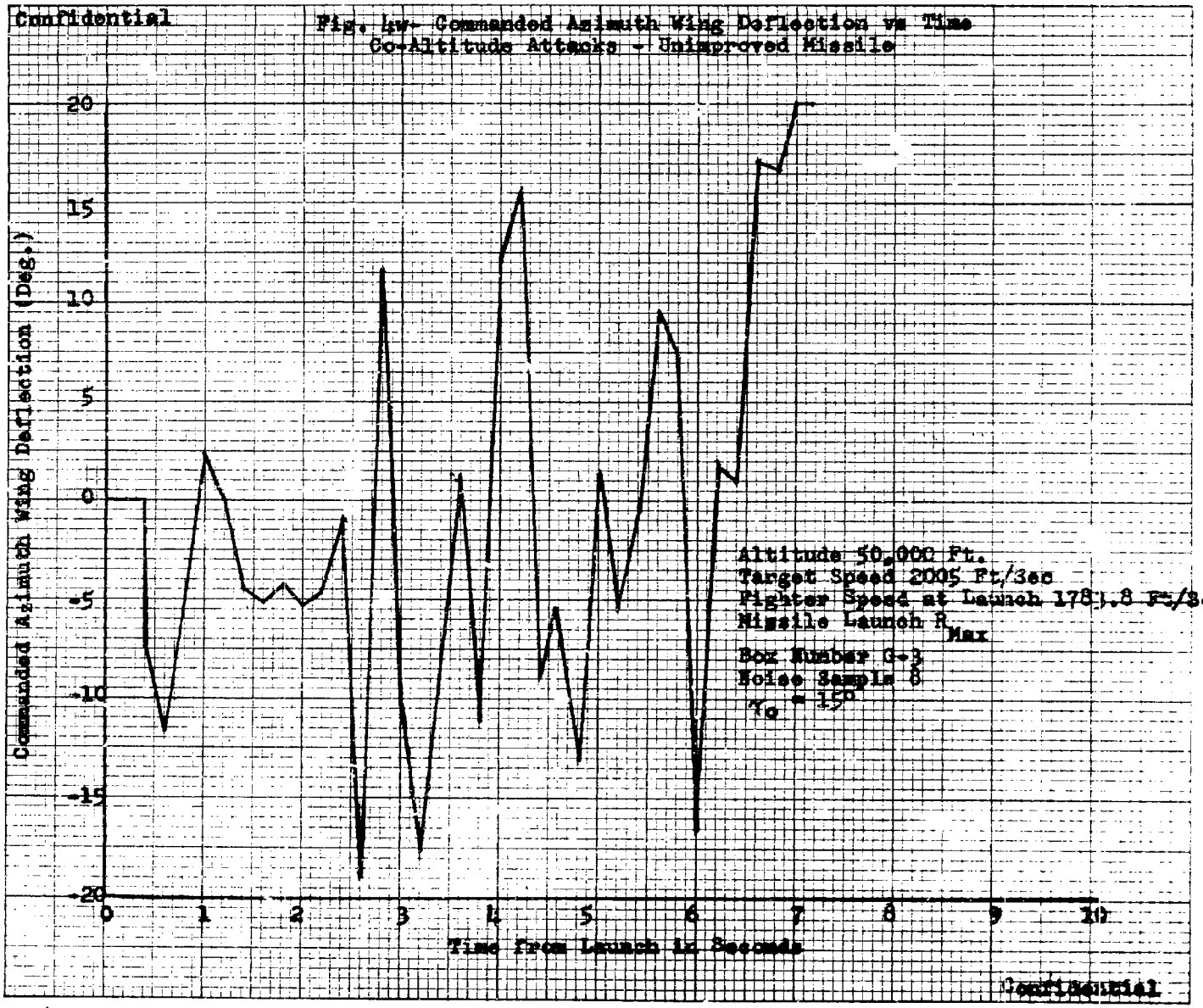
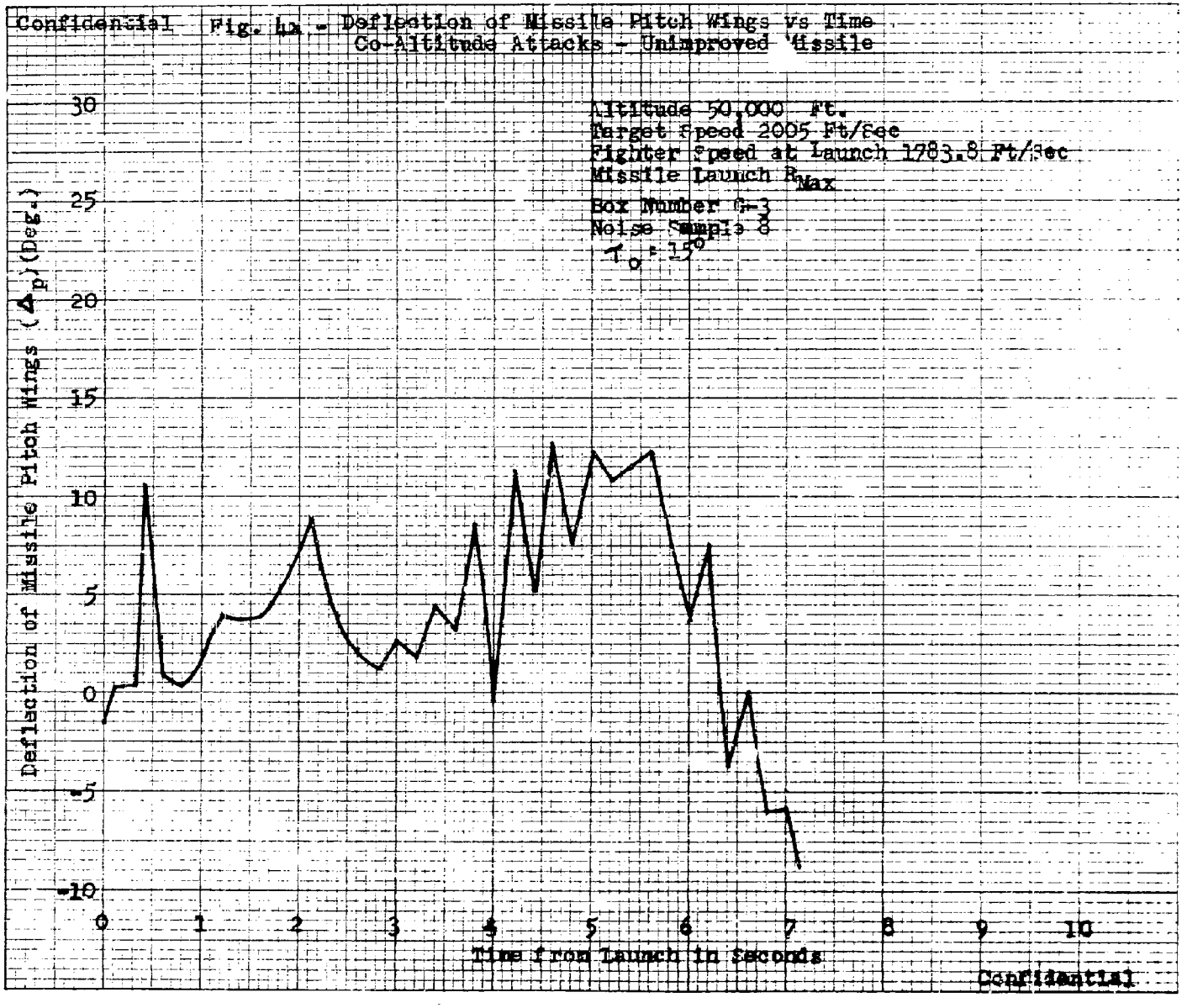


Fig. 4w- Commanded Azimuth Wing Deflection vs Time
Co-Altitude Attacks - Unimproved Missile





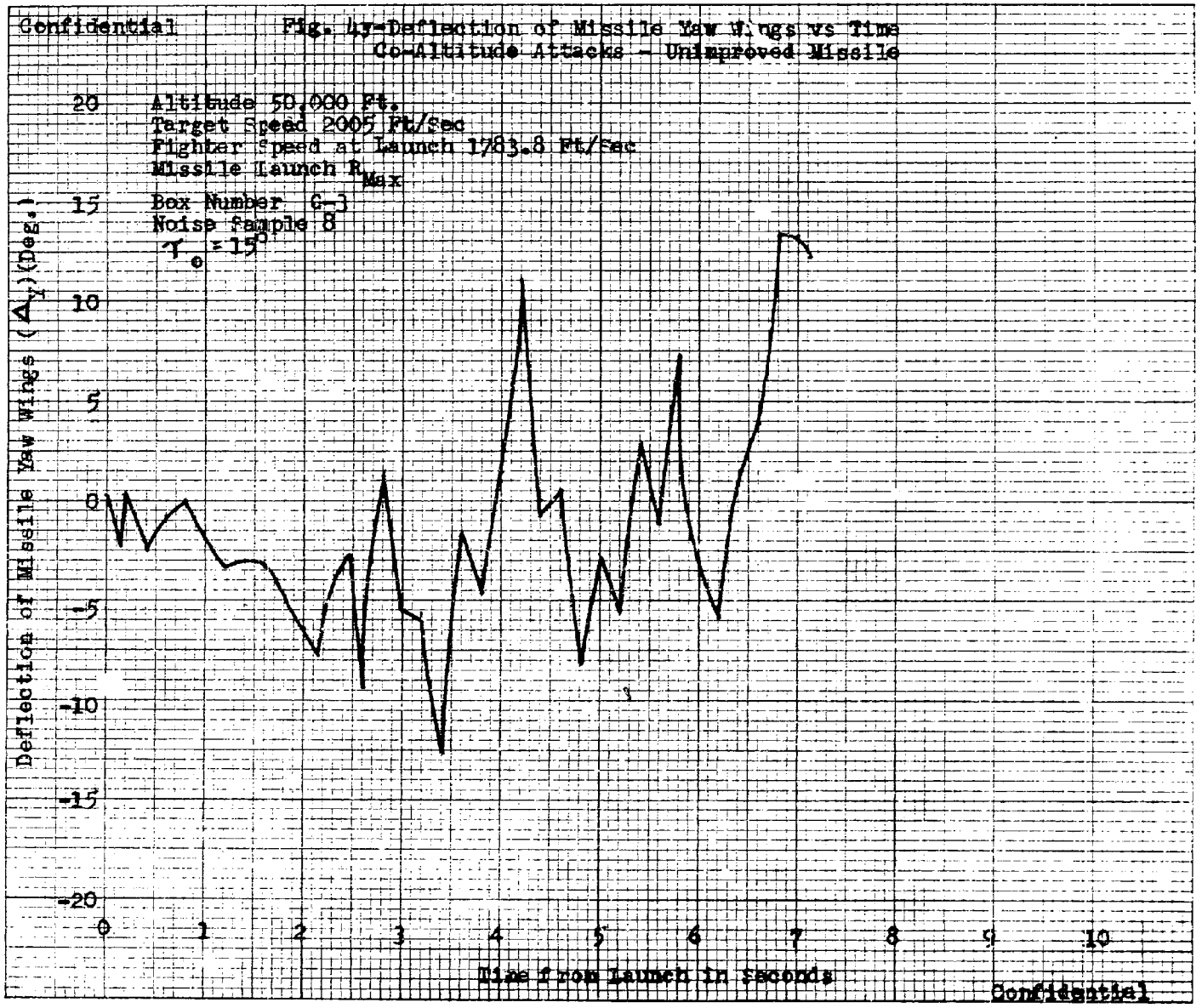

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Fig. 47-Deflection of Missile Yaw Wings vs Time
Co-Altitude Attacks - Unimproved Missile
Altitude 50,000 Ft.
Target Speed 2005 Ft/Sec
Fighter Speed at Launch 1783.8 Ft/Sec
Missile Launch R Max
Box Number C-3
Noise Sample 8
γo -15°
Deflection of Missile Yaw Wings (Δγ)(Deg.)
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
10
Time from Launch in Seconds
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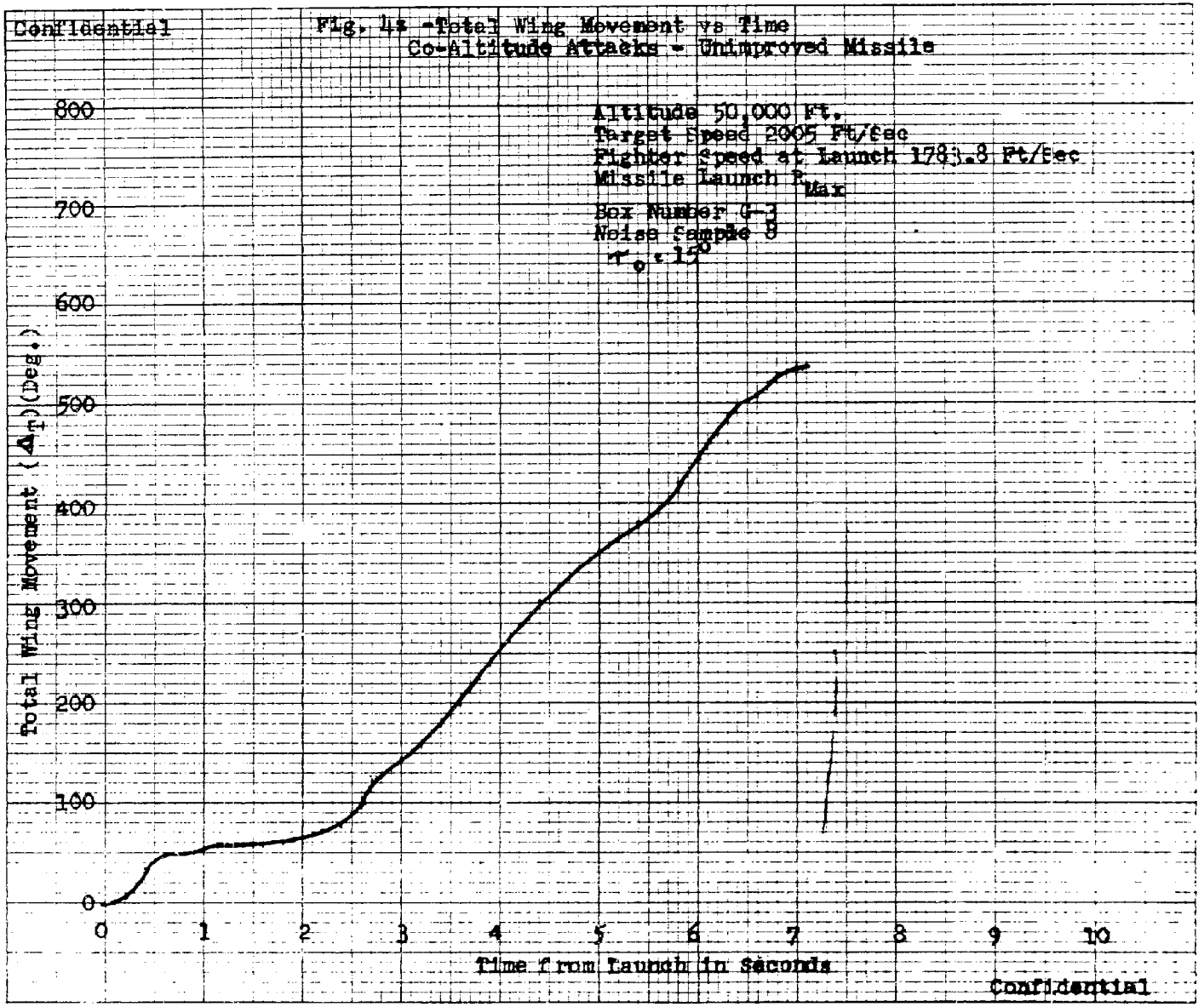

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Fig. 5a - Sparrow III Miss Distance-Co-Altitude Attack
X-Y Miss Distance at the Target
$\gamma_0 = 60°$, R_{max} Launch, Fighter Course - D-1
Unimproved Missile

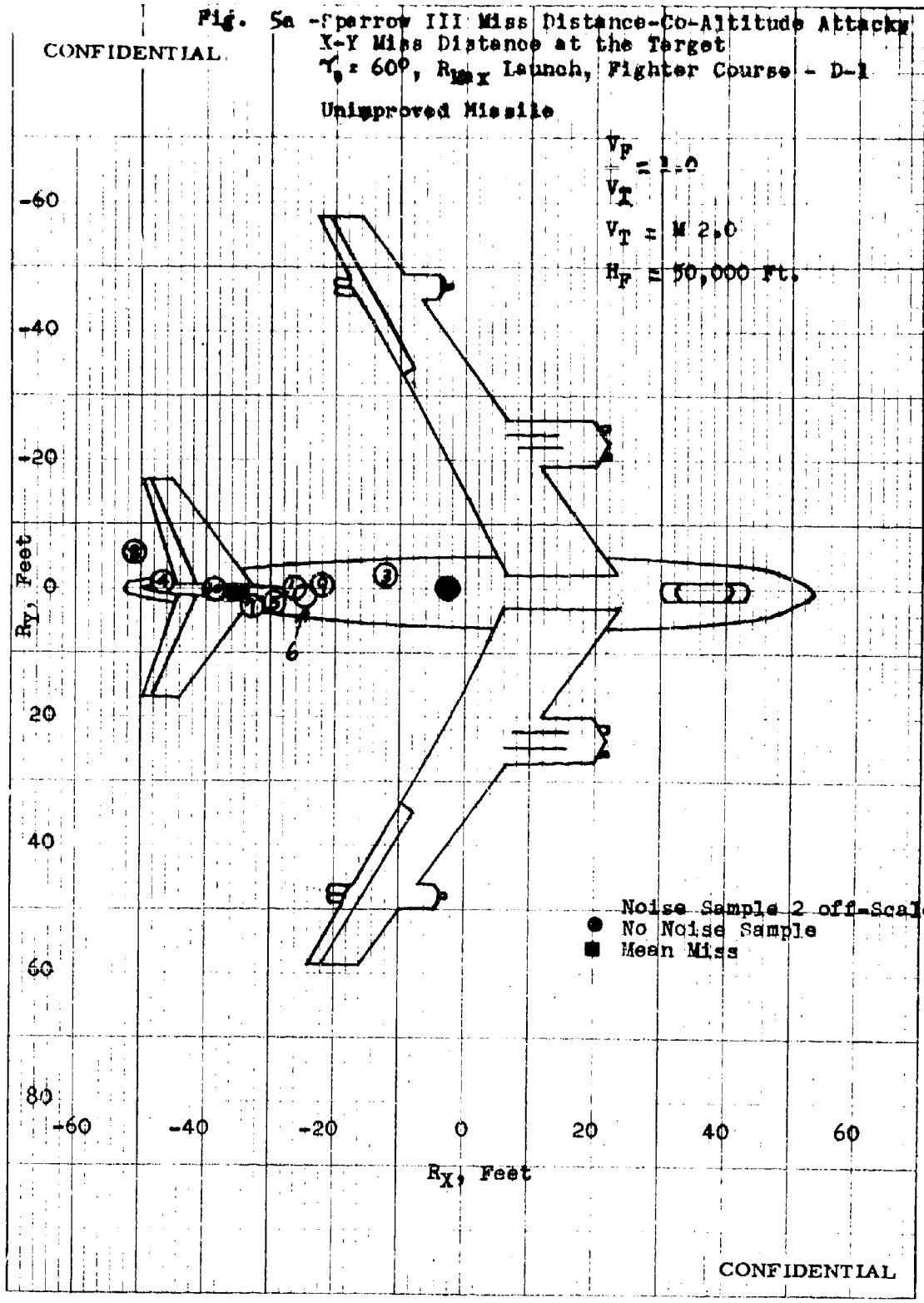

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Fig. 5b Sparrow III Miss Distance - Co-altitude Attacks
X-2 Miss Distance at the Target
$T_o = 60^0$, R_{max} Launch, Fighter Course - B-1
Unimproved Missile

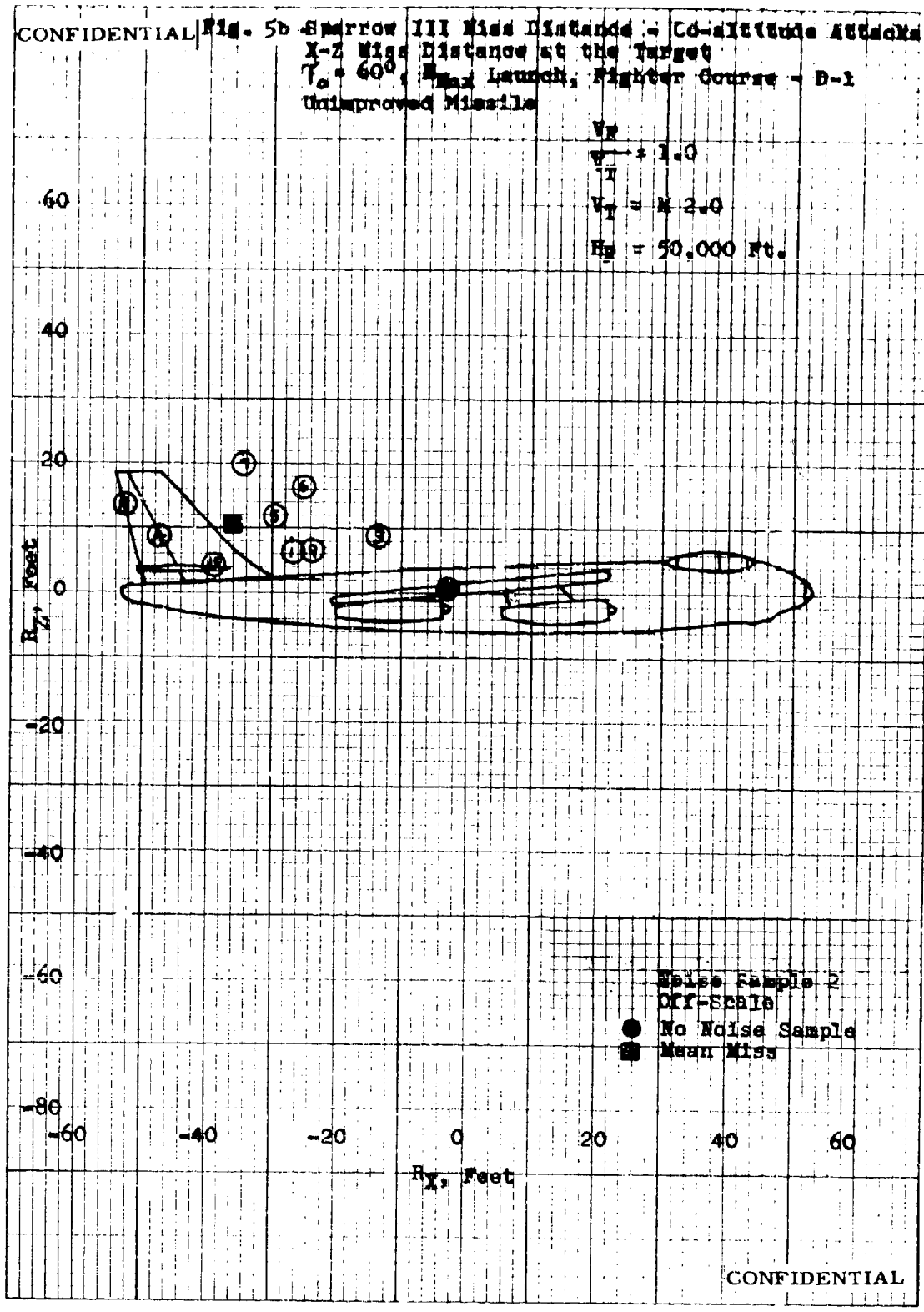

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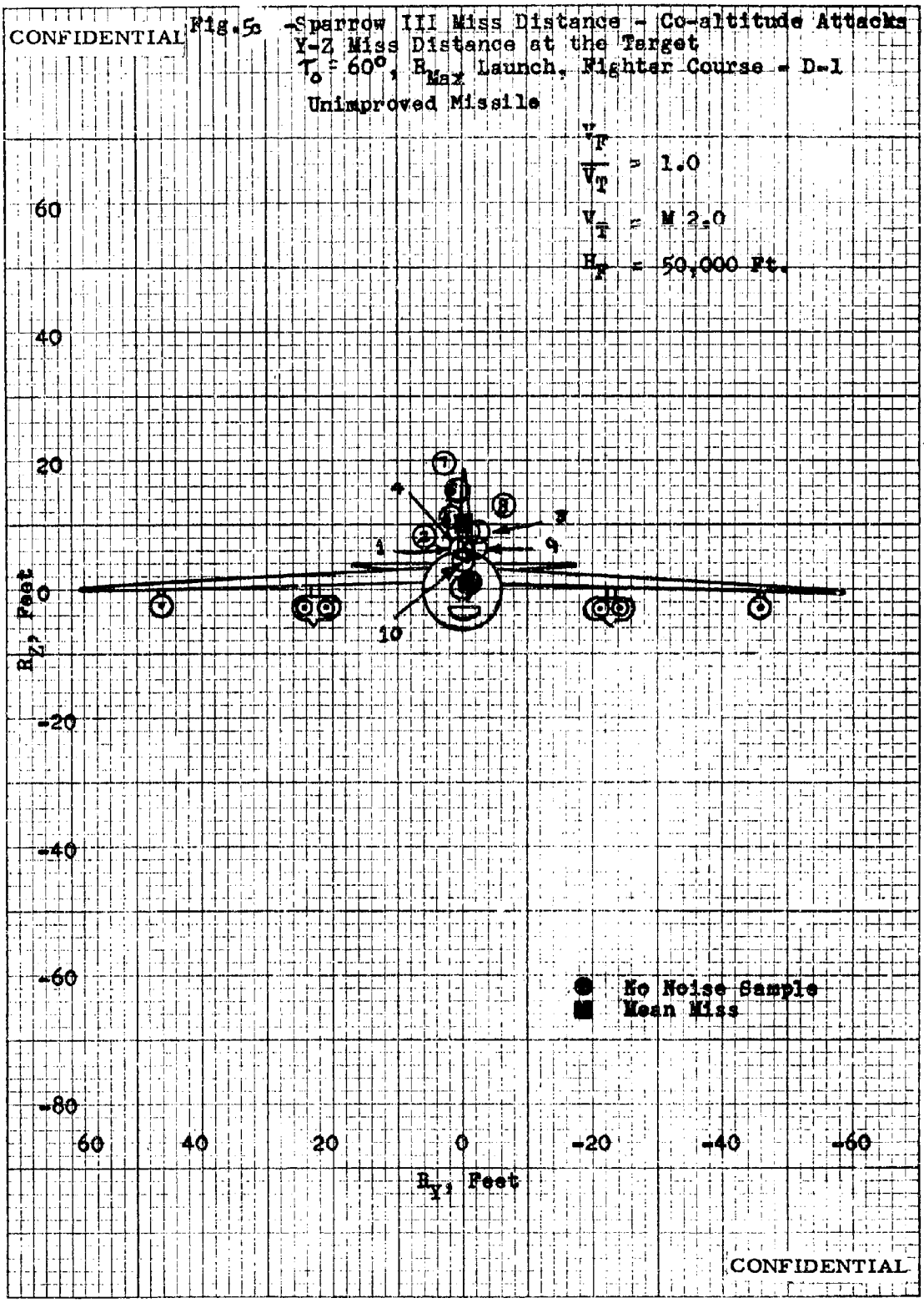
Fig. 5a -Sparrow III Miss Distance - Co-altitude Attacks
Y-Z Miss Distance at the Target
$\tau_o = 60°$, R_{Max} Launch, Fighter Course - D-1
Unimproved Missile



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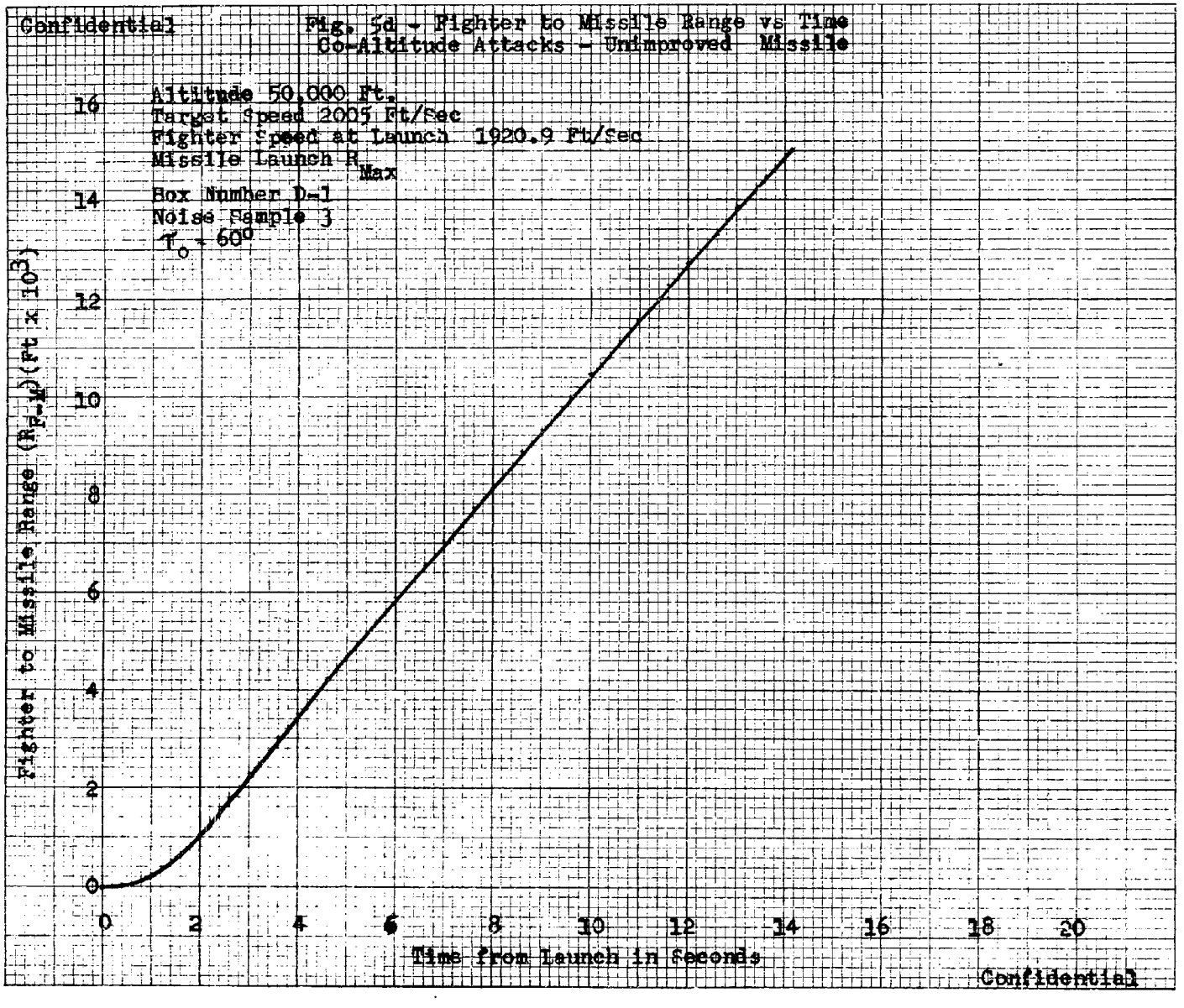


Fig. 5a - Missile to Target Range vs Time
Co-Altitude Attacks - Unimproved Missile

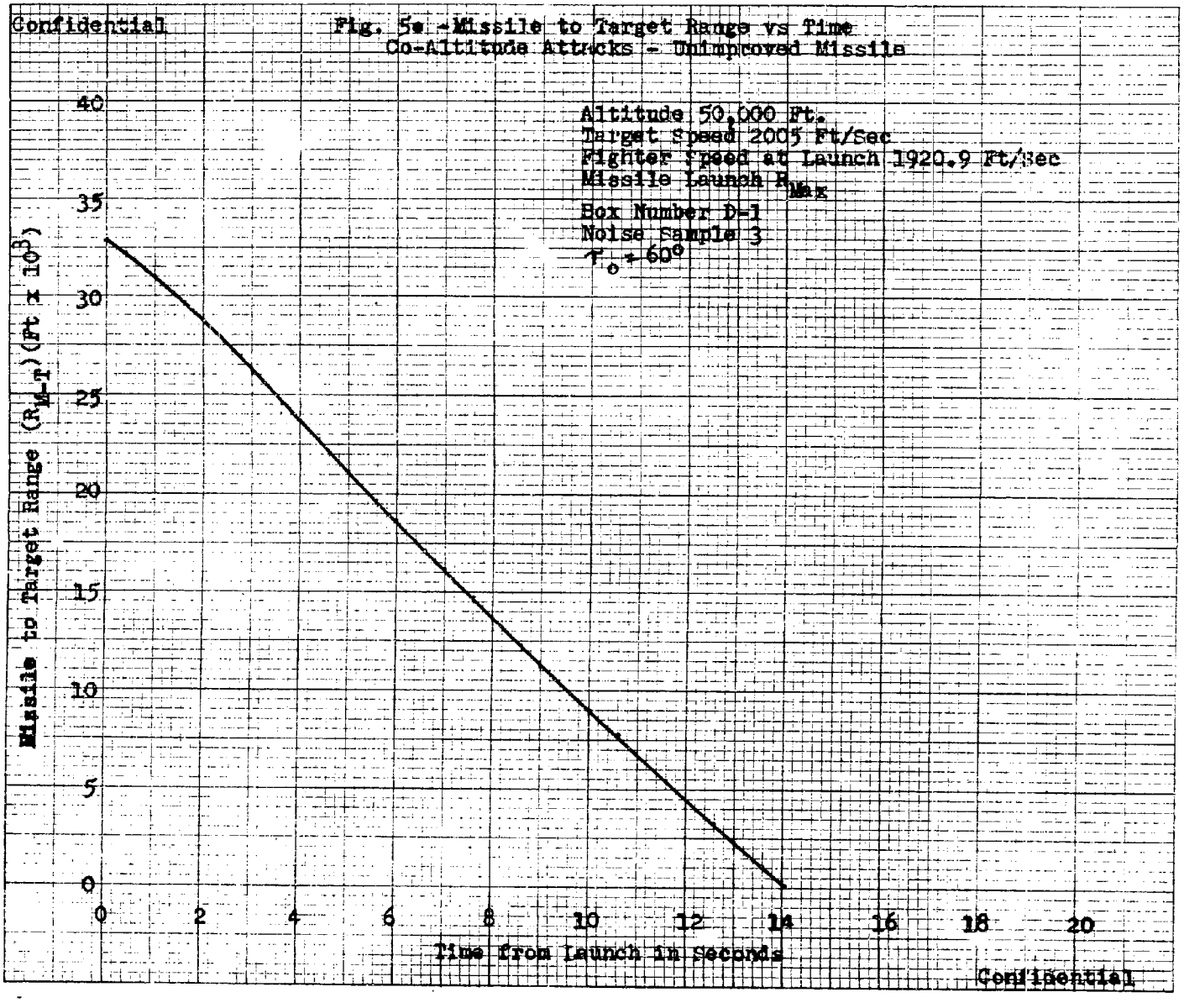


Fig. 5r - Fighter to Target Range vs Time
Co-Altitude Attacks - Unimproved Missile

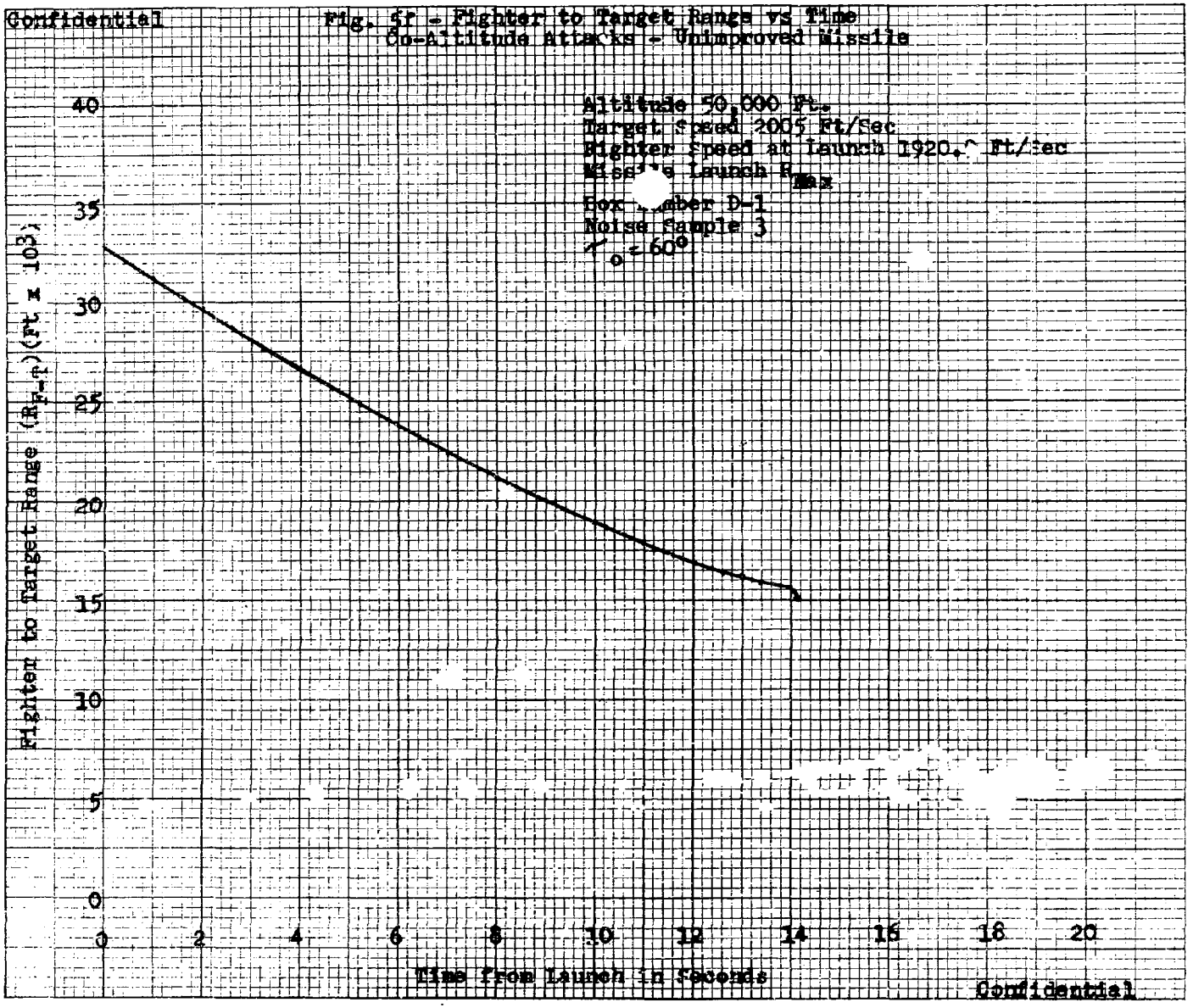
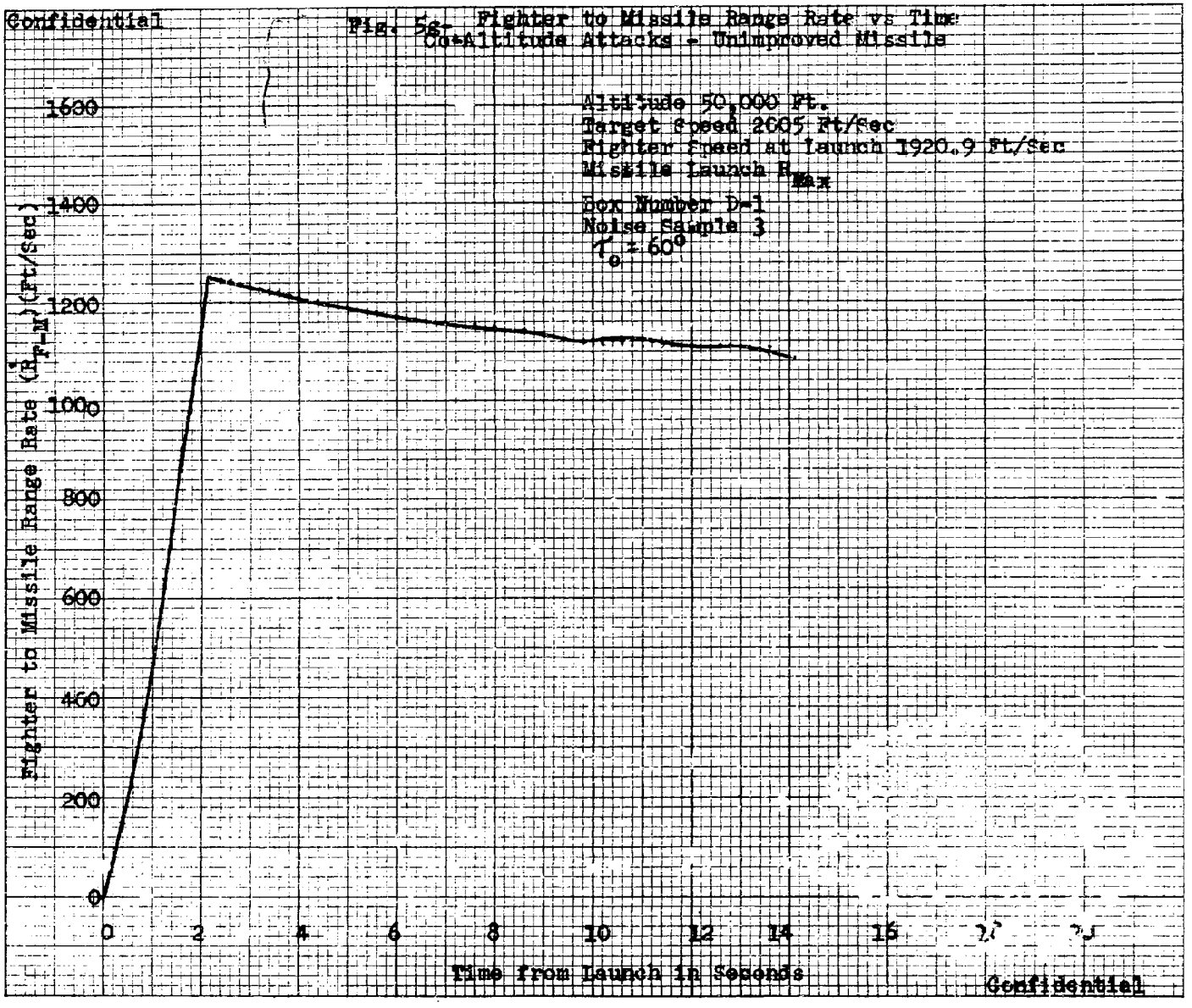


Fig. 56. Fighter to Missile Range Rate vs Time
Co-Altitude Attacks - Unimproved Missile



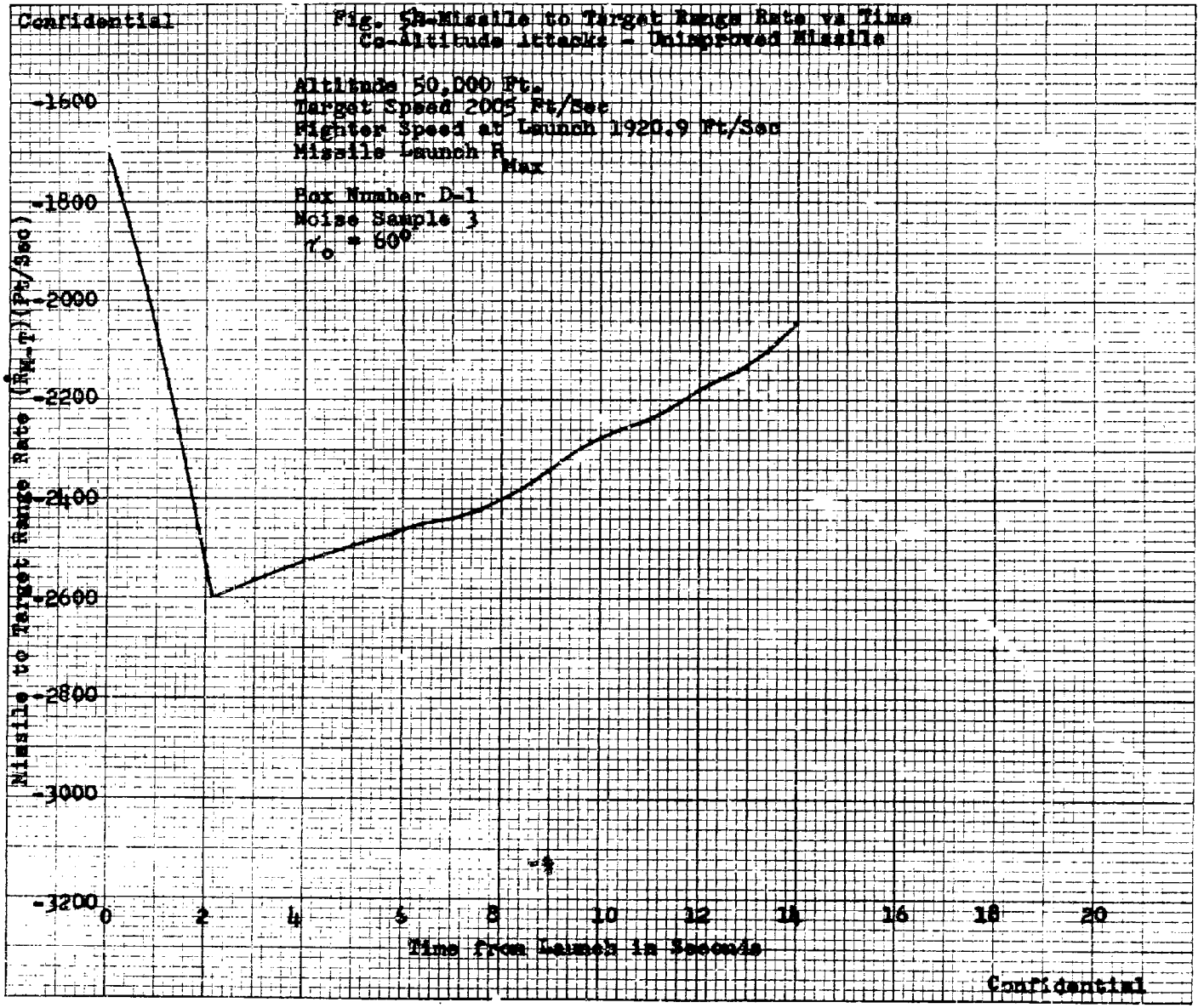
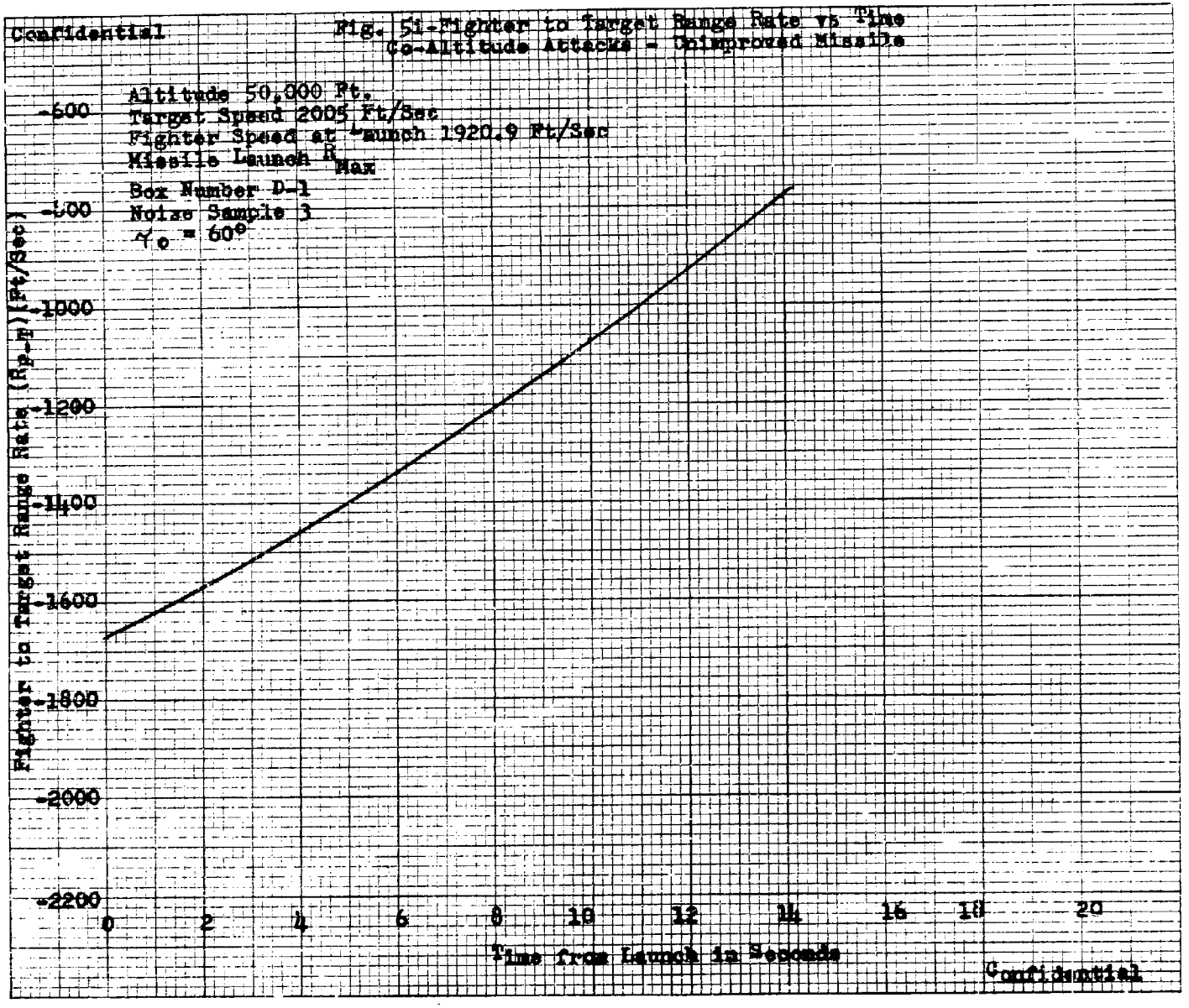


Fig. 51-Fighter to Target Range Rate vs Time
Co-Altitude Attacks - Unimproved Missile



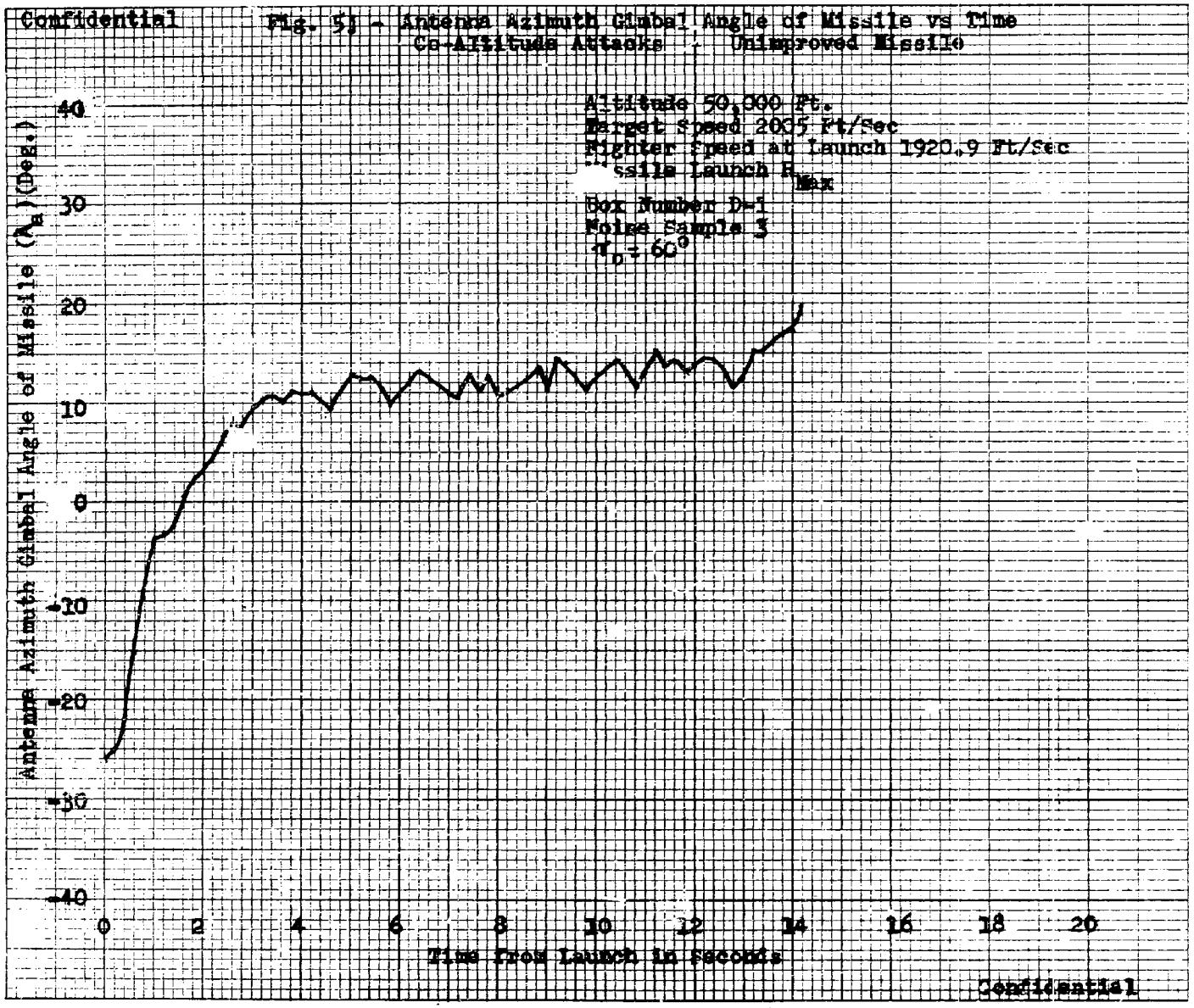


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Fig. 5k - Antenna Elevation Gimbal Angle of Missile vs Time
Co-Altitude Attacks - Unimproved Missile

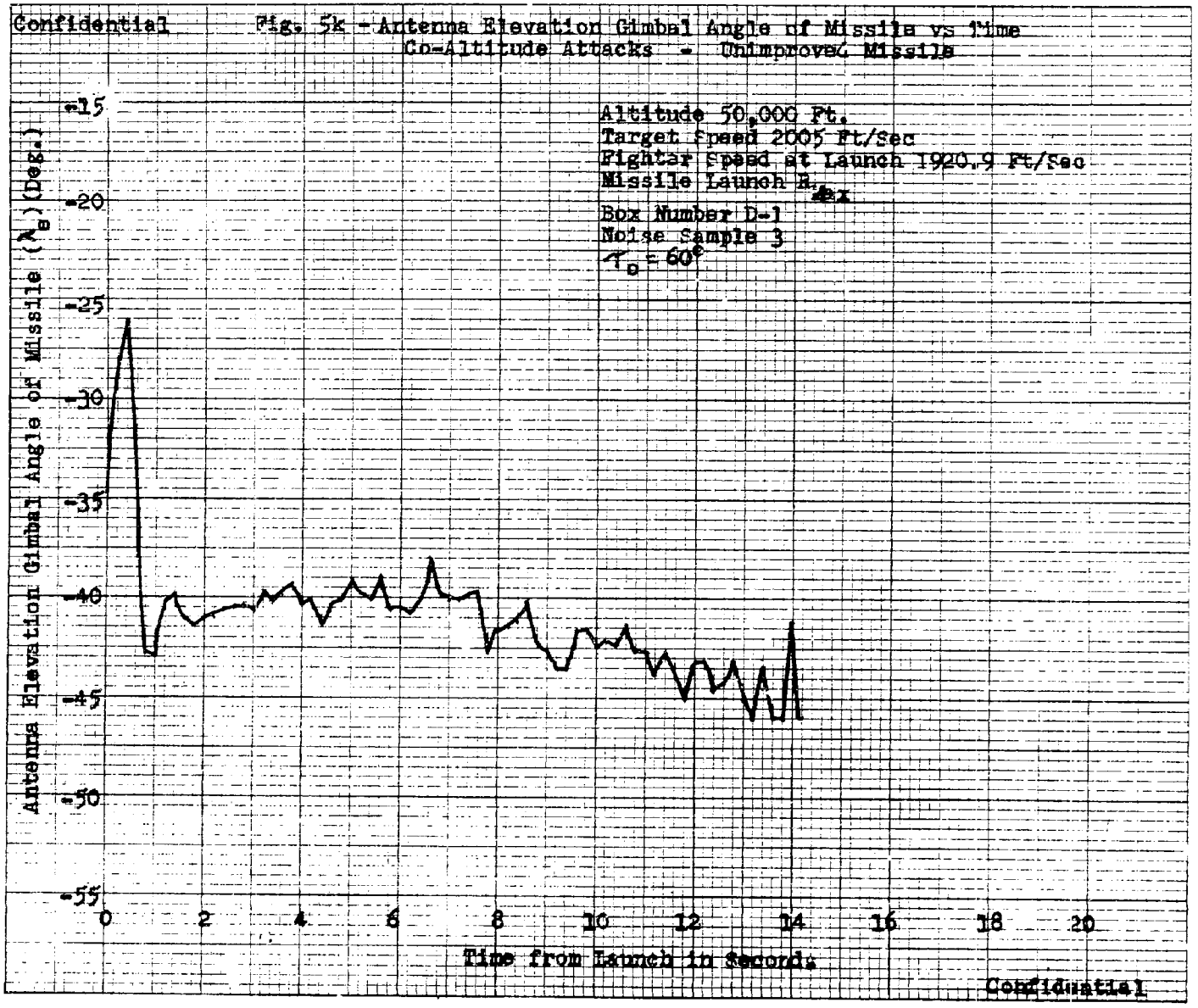

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Fig. 51 - Missile Lead Angle vs Time
Co-Altitude Attacks - Unimproved Missile

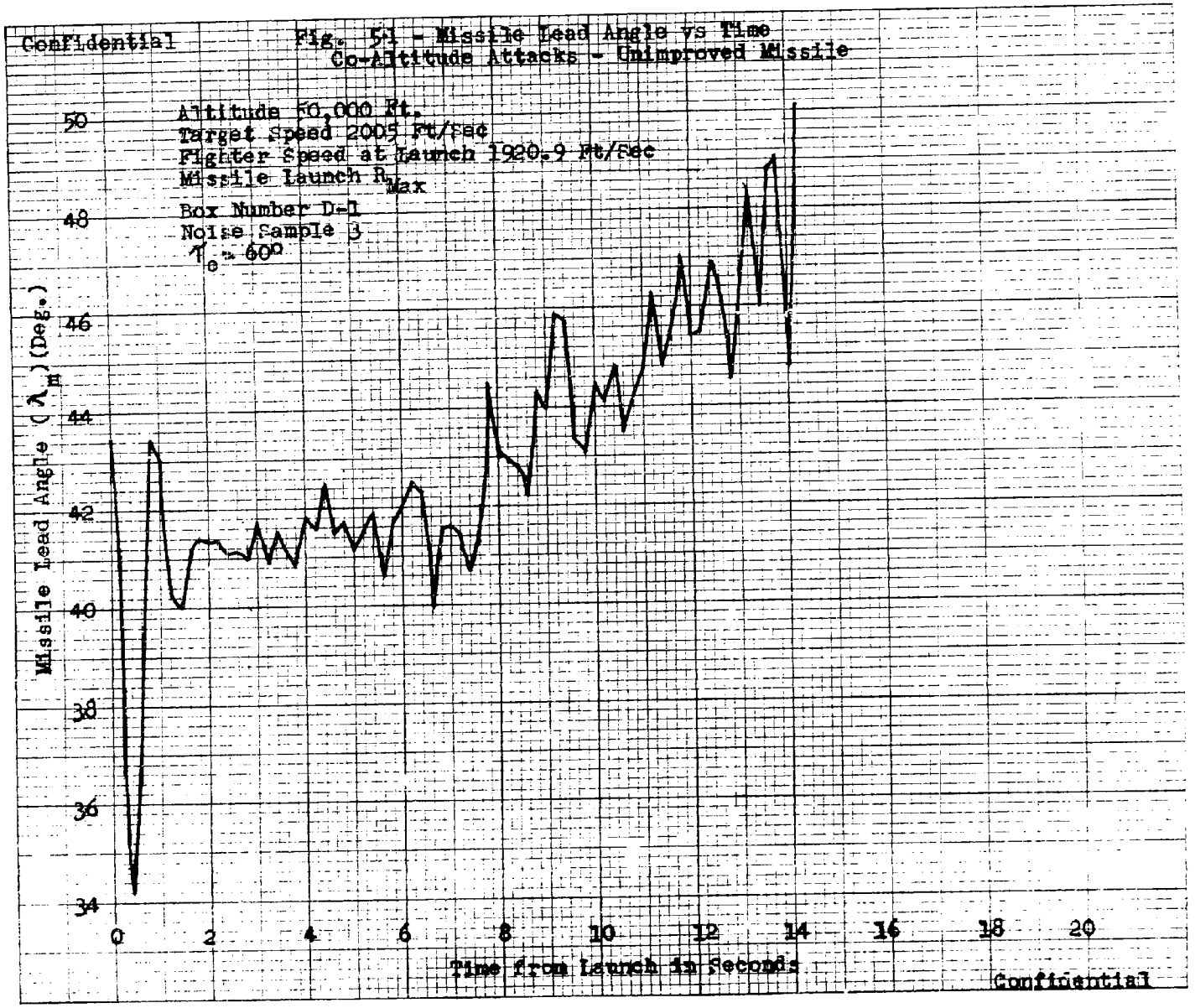

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Fig. 5m - Azimuth Line of Sight Rate of Missile vs Time
Co-Altitude Attacks - Unimproved Missile

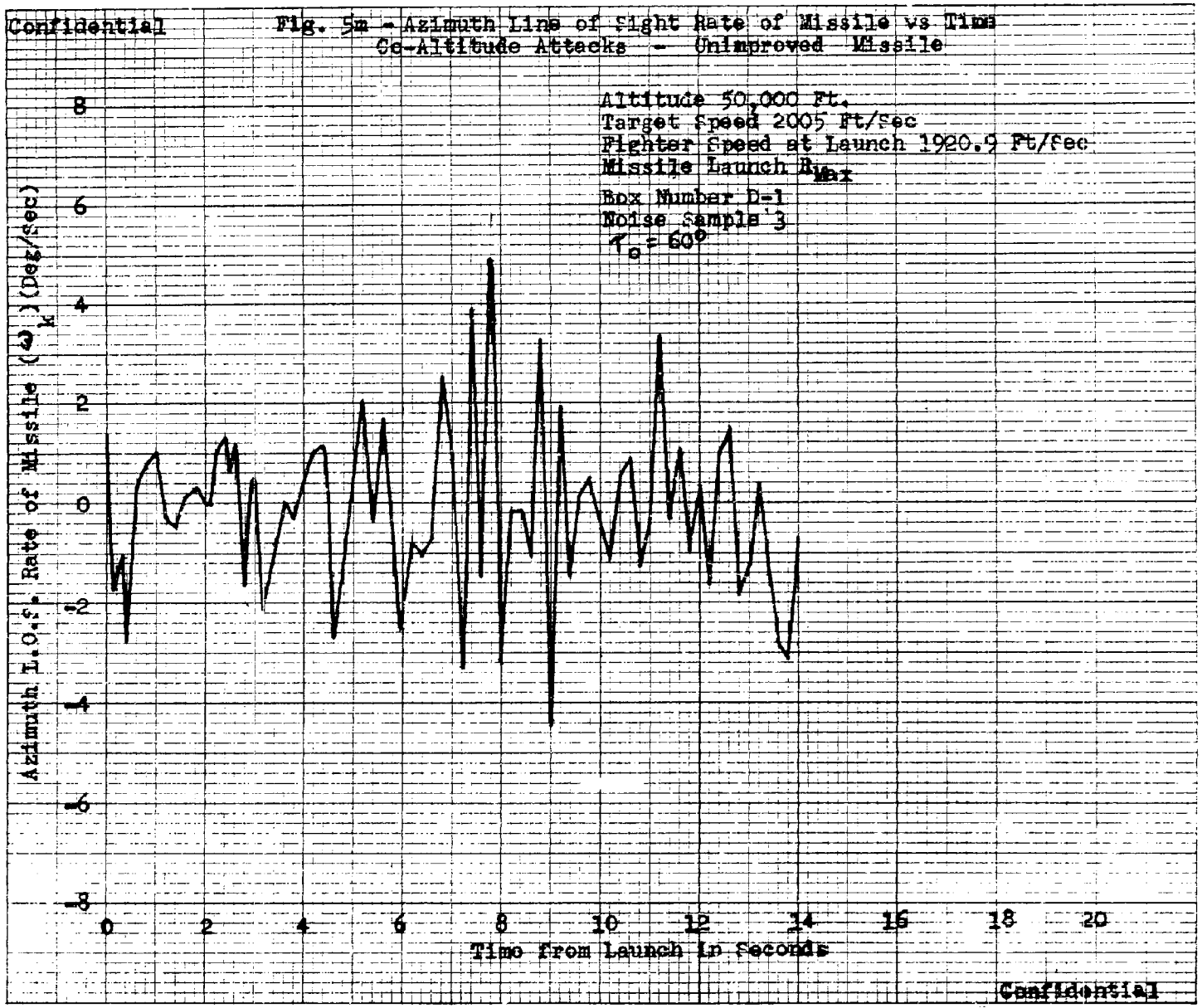

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Fig. 5a-Elevation Line of Sight Rate of Missile vs Time
Co-Altitude Attacks - Unimproved Missile

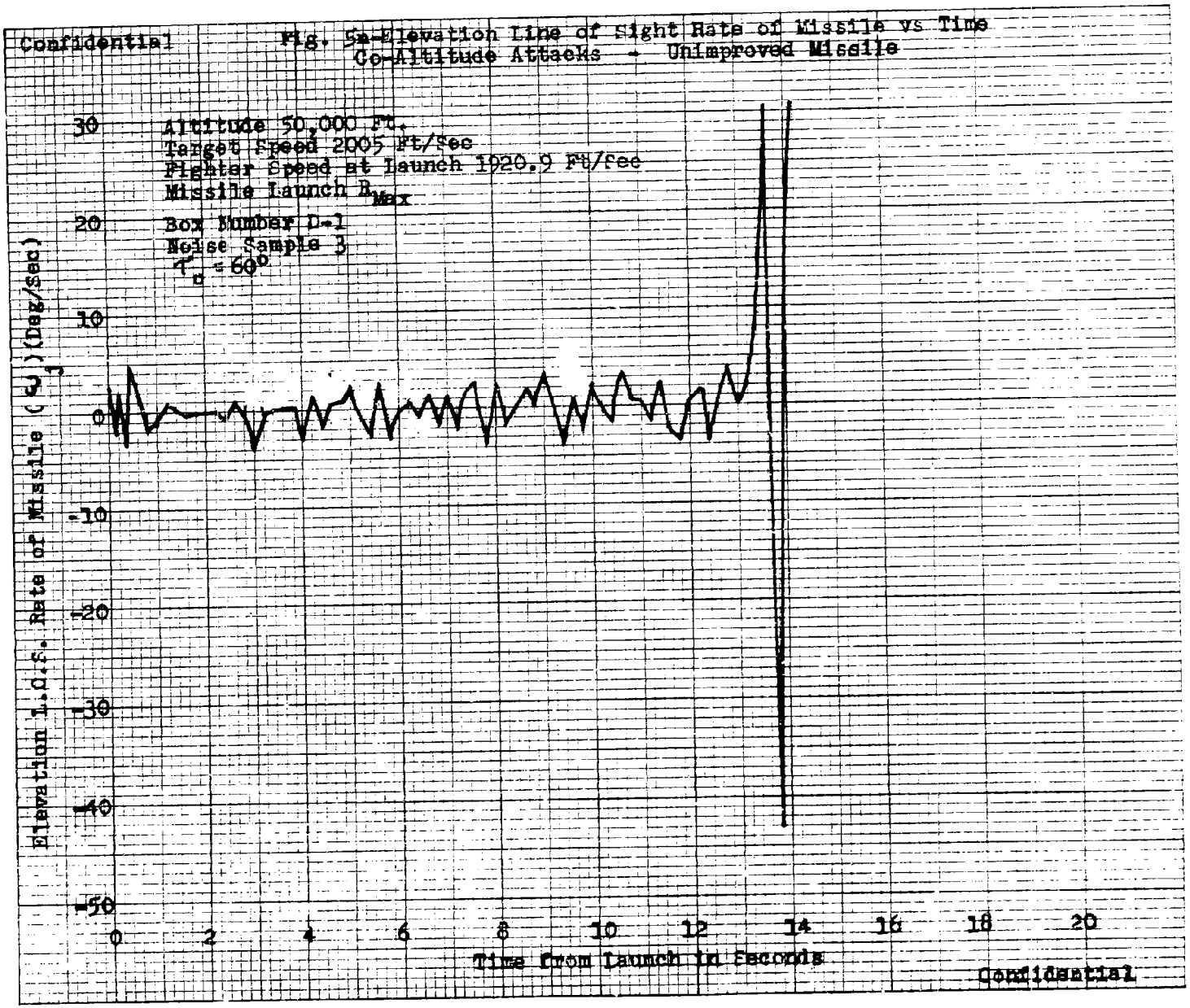


Fig. 5a - Missile Velocity vs Time
Co-Altitude Attacks - Unimproved Missile

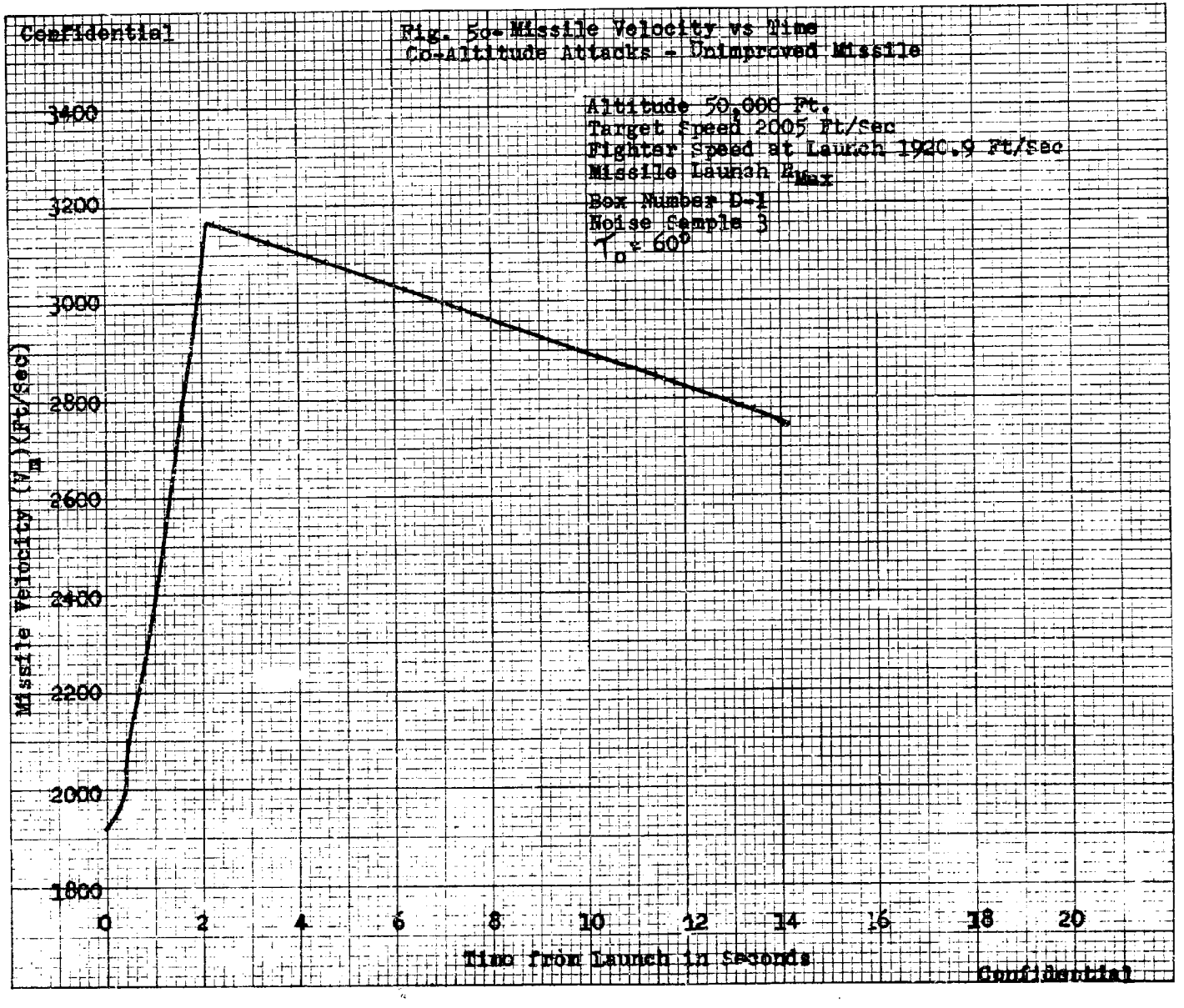


Fig. 5p - Azimuth Look-Angle Error for Missile Seeker Vs Time
Co-Altitude Attacks - Unimproved Missile

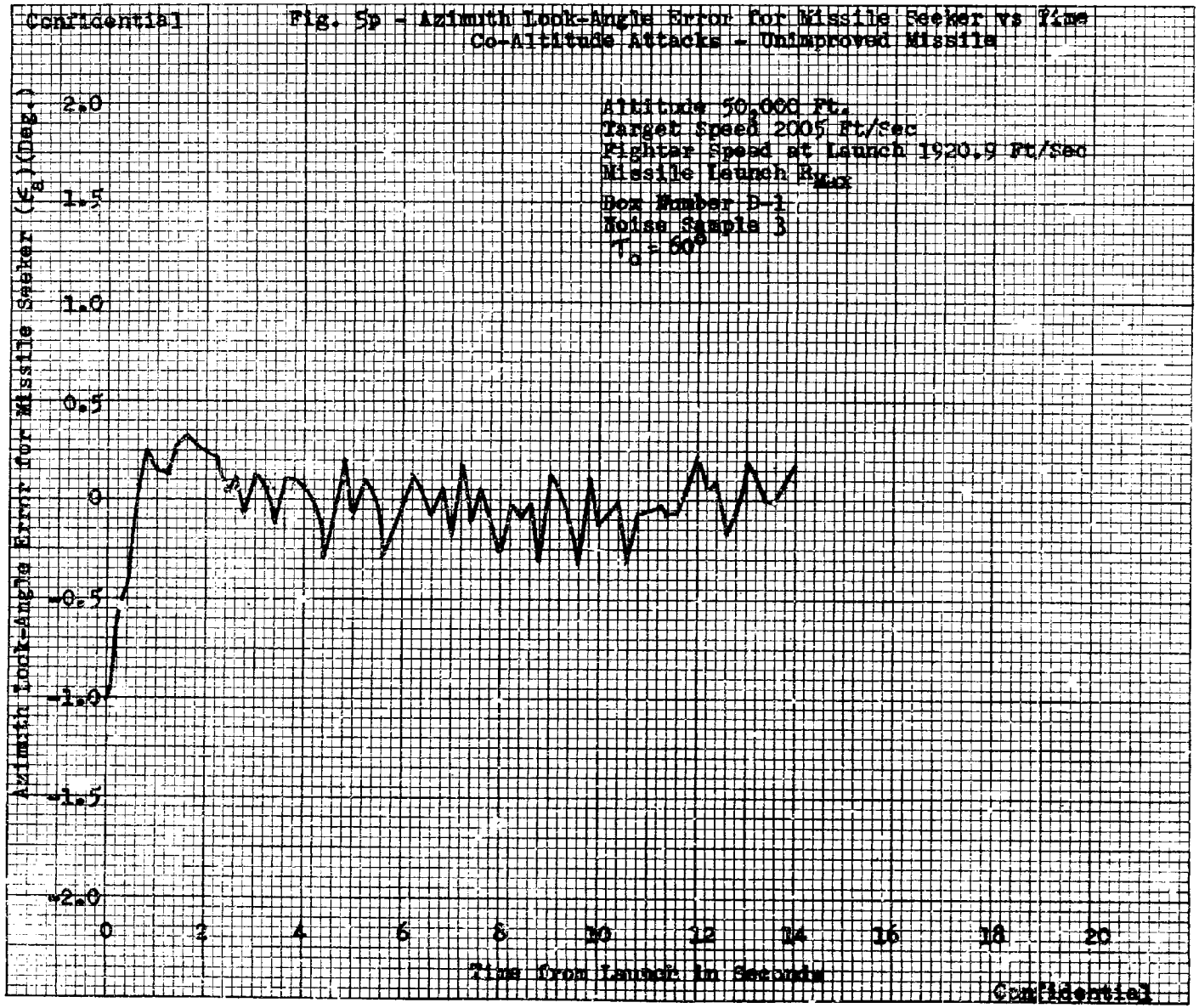
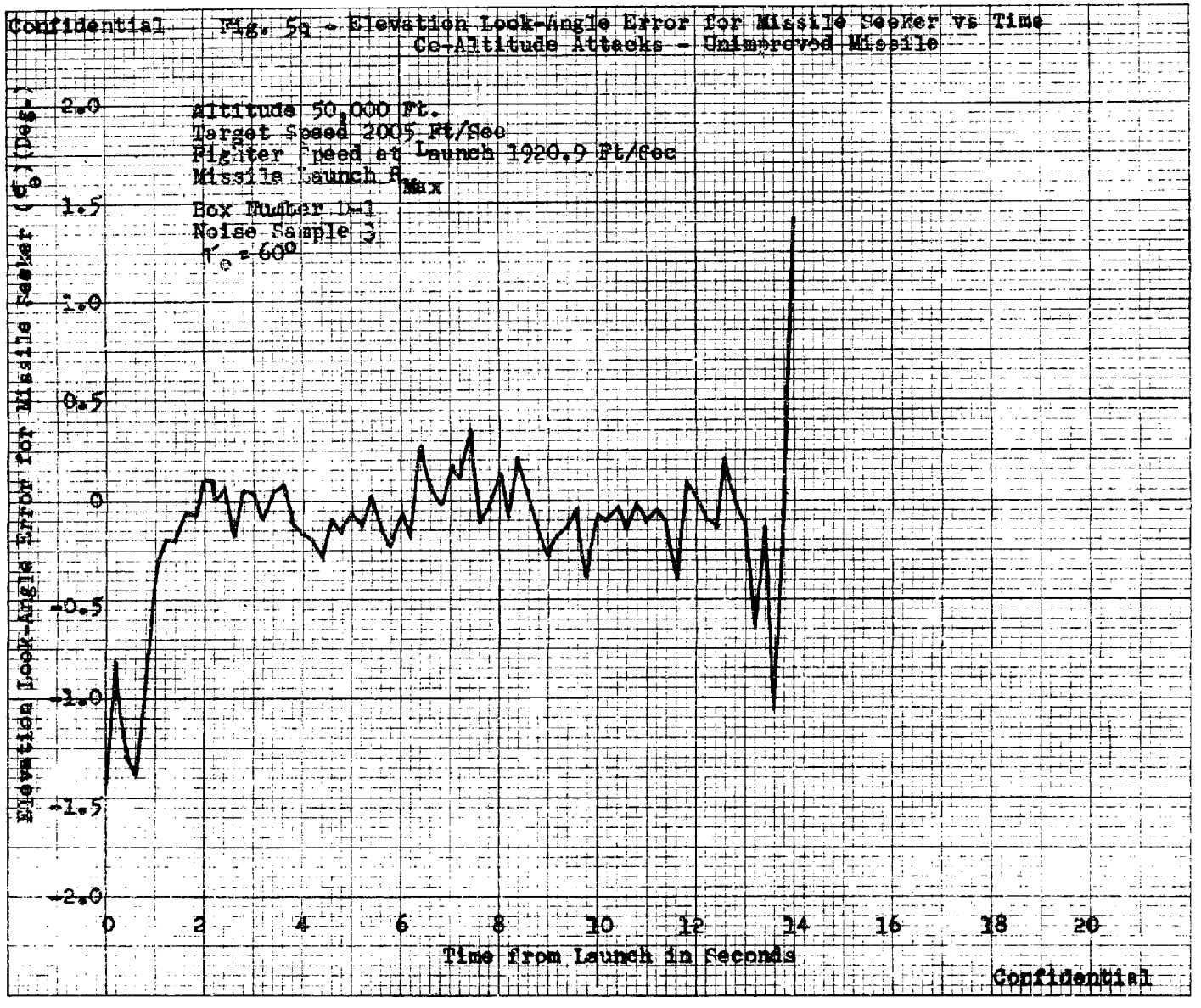


Fig. 5q - Elevation Lock-Angle Error for Missile Seeker vs Time
Ce-Altitude Attacks - Unimproved Missile



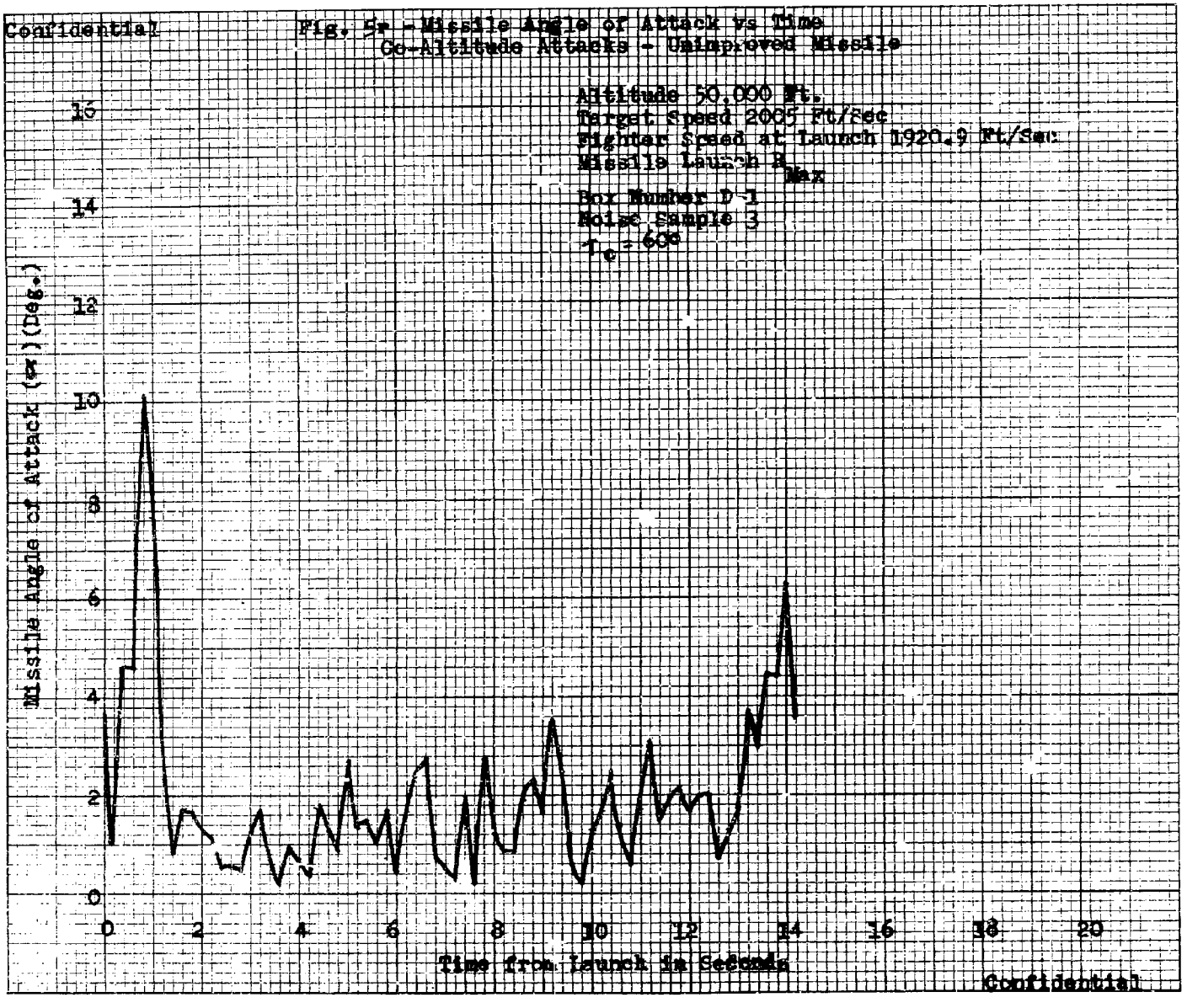
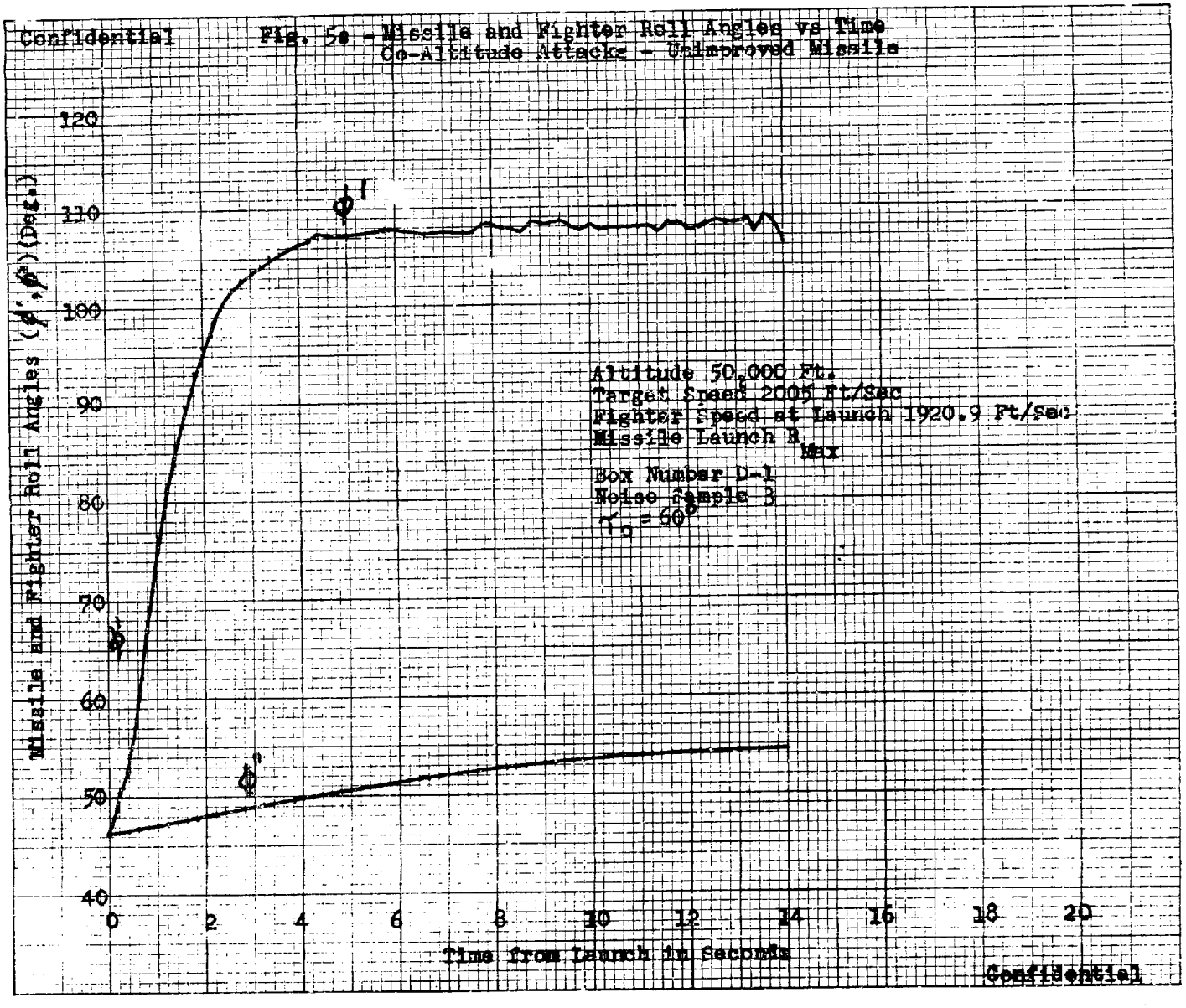
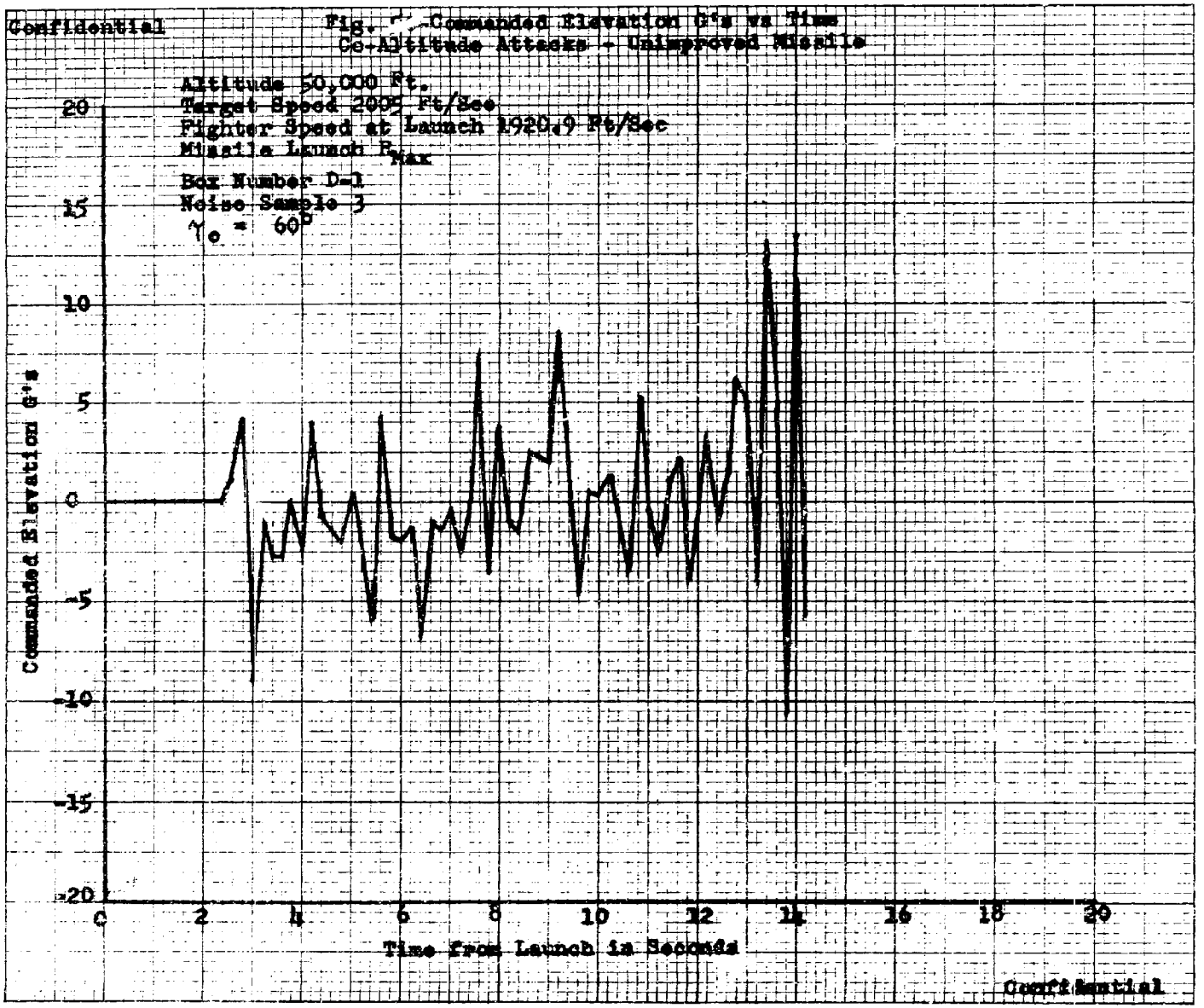


Fig. 5a - Missile and Fighter Roll Angles vs Time
Co-Altitude Attacks - Unimproved Missile





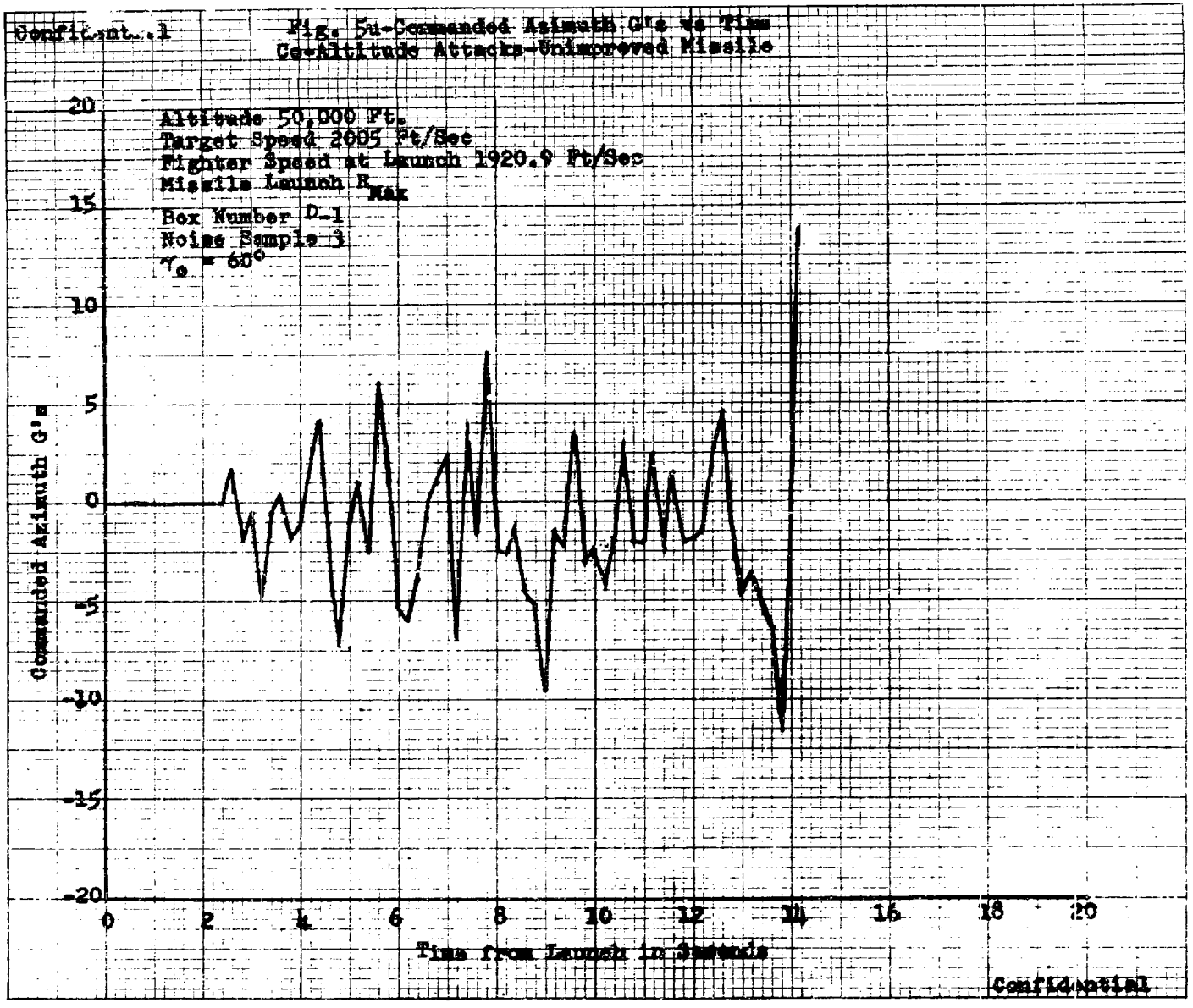

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Fig. 5u-Commanded Azimuth G's vs Time
Co-Altitude Attacks-Unimproved Missile
Altitude 50,000 Ft.
Target Speed 2005 Ft/Sec
Fighter Speed at Launch 1920.9 Ft/Sec
Missile Launch R Max
Box Number D-1
Noise Sample 3
γ_o = 60°
Commanded Azimuth G's
Time from Launch in Seconds
20
15
10
5
0
-5
-10
-15
-20
0
2
4
6
8
10
12
14
16
18
20
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Fig. 5v-Commanded Elevation Wing Deflection vs Time
Co-Altitude Attacks - Unimproved Missile

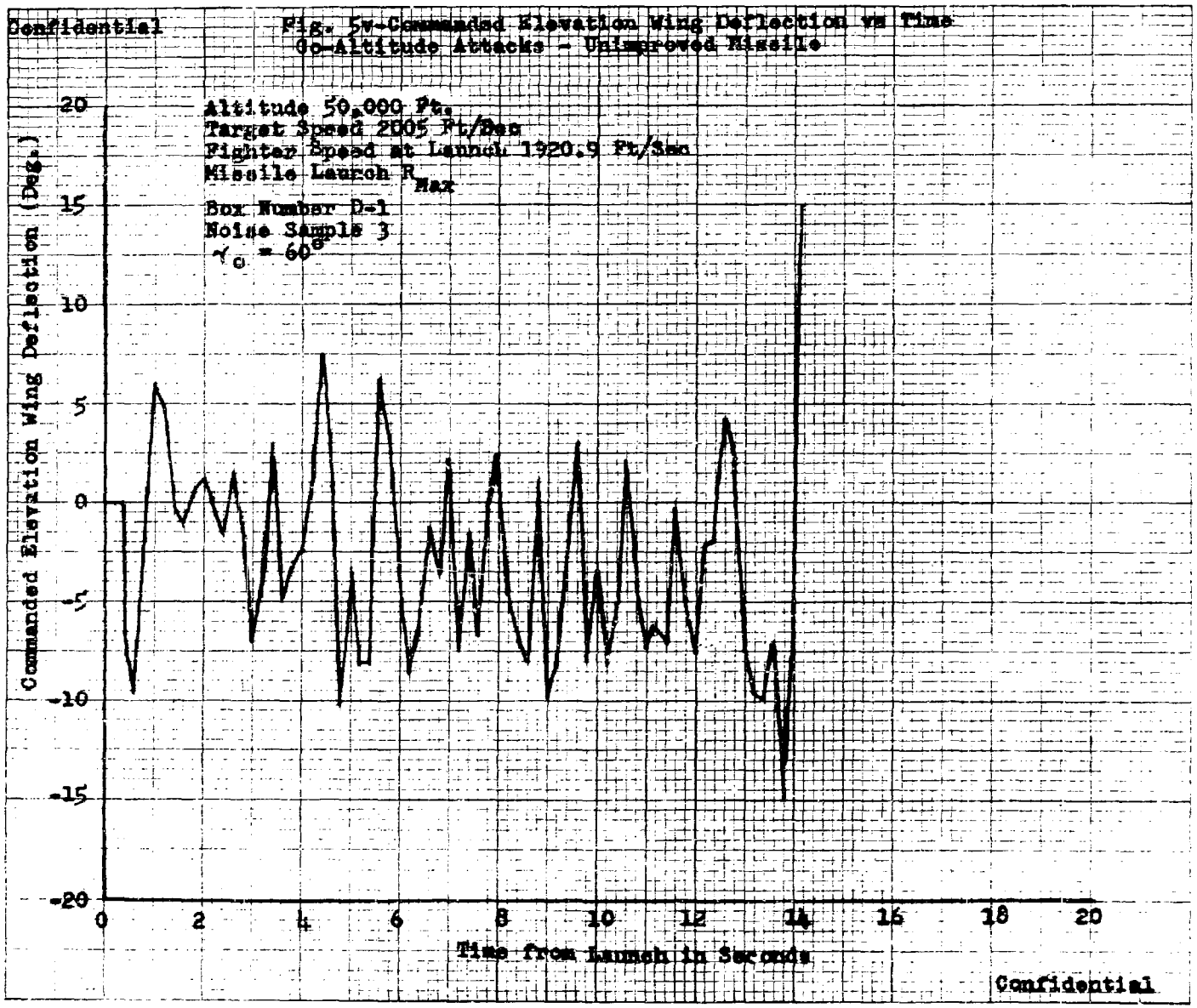

Fig. 5w-Commanded Azimuth Wing Deflection vs Time
Cs-Altitude Attacks - Unimproved Missile

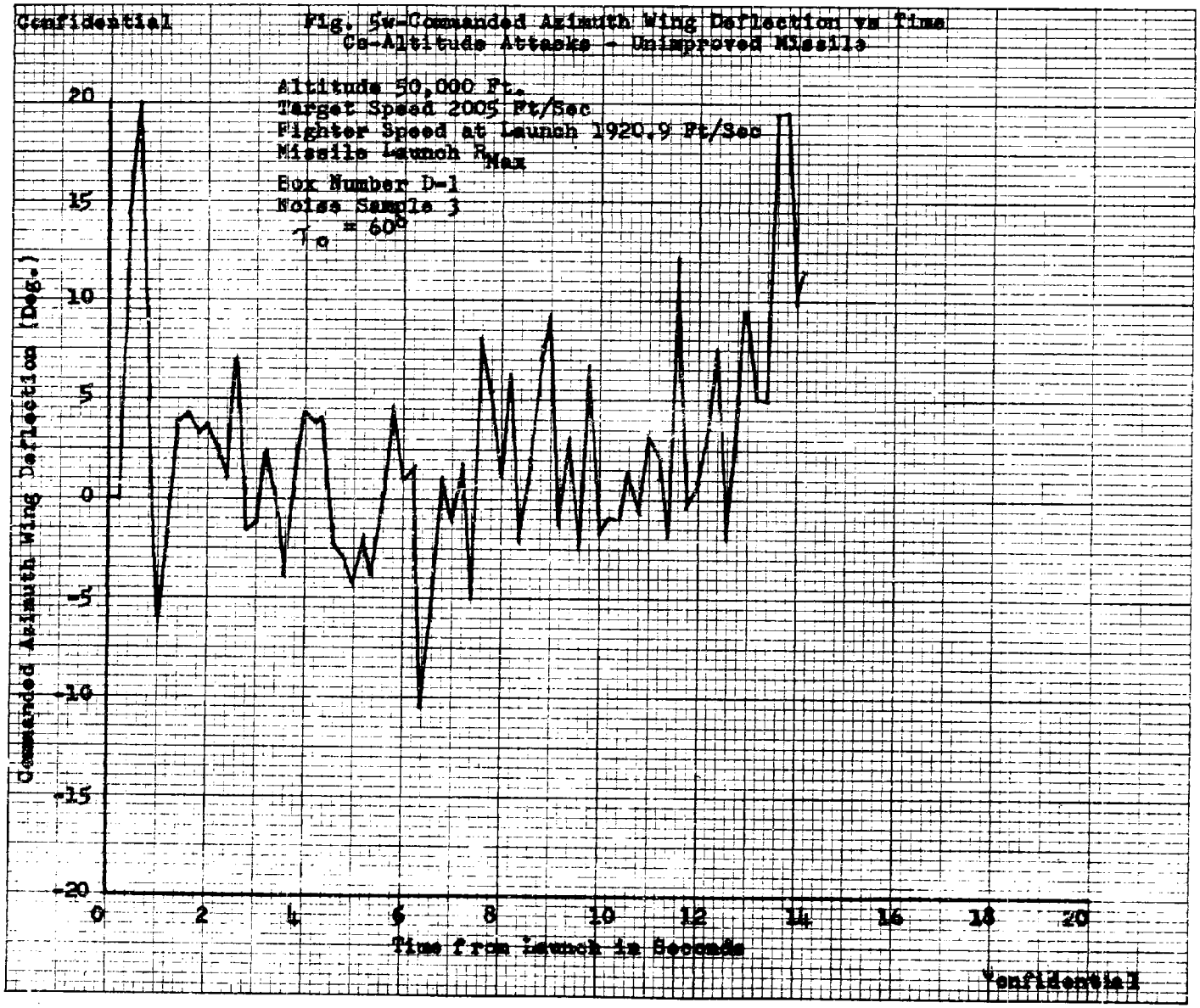

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Fig. 5 - Deflection of Missile Pitch Wings vs Time
Co-Altitude Attacks - Unimproved Missile

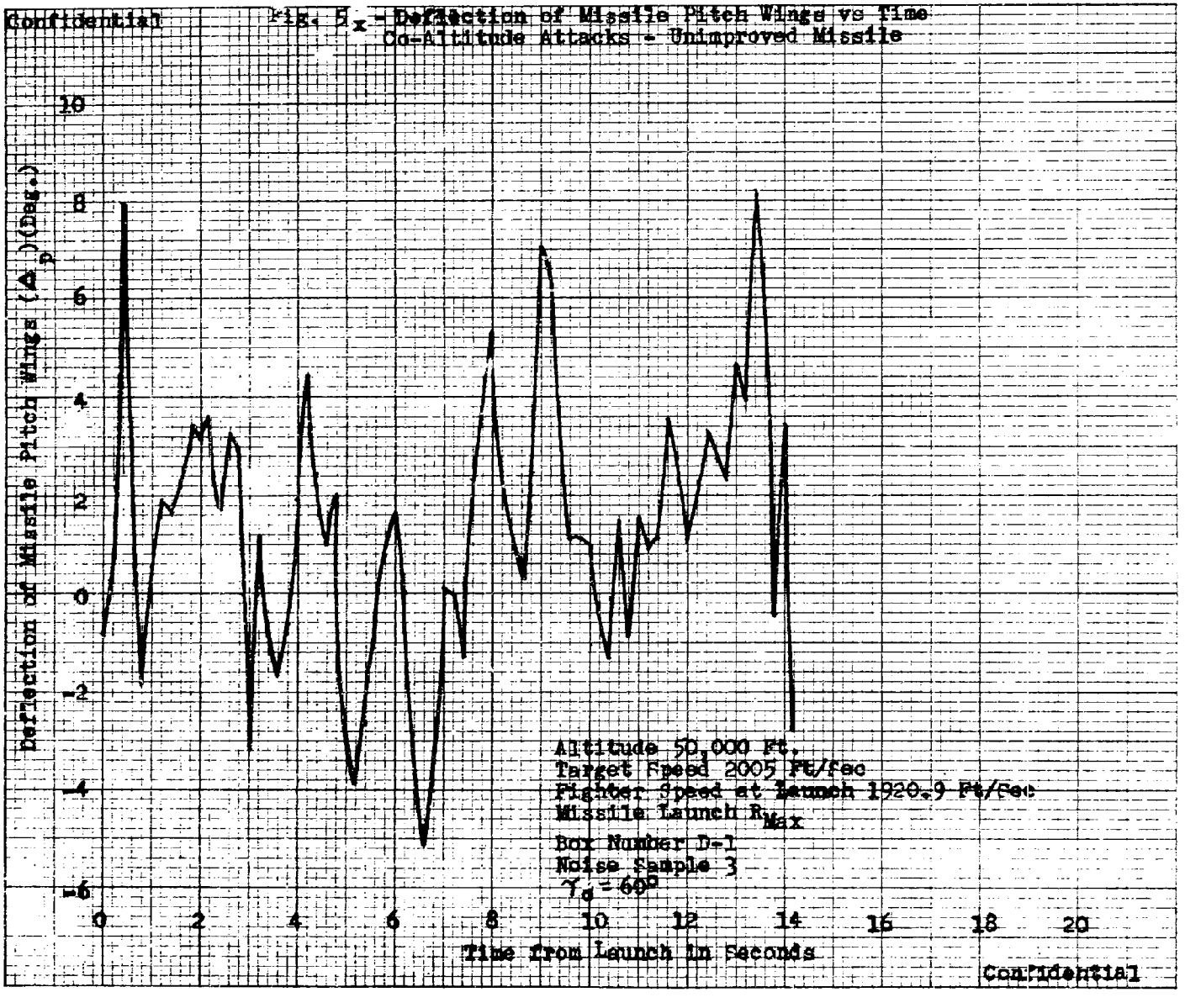

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Fig. 57 -Deflection of Missile Yaw Wings vs Time
Co-Altitude Attacks - Unimproved Missile

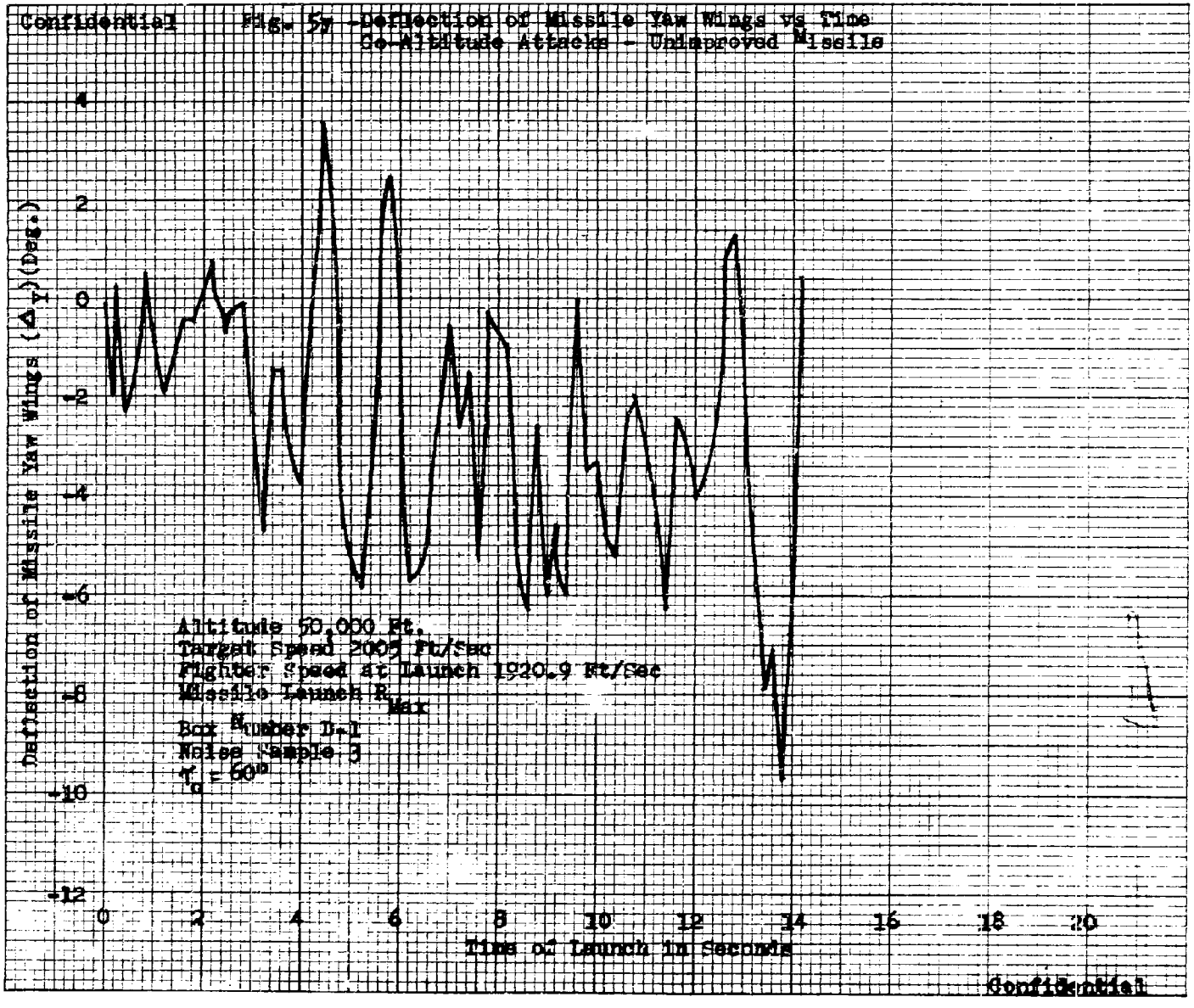

Fig. 5s - Total Wing Movement vs Time
Co-Altitude Attacks - Unimproved Missile

Altitude 50,000 Ft.
Target Speed 2005 Ft/Sec
Fighter Speed at Launch 1920.9 Ft/Sec
Missile Launch R_{Max}
Box Number D-1
Noise Sample 3
$\Psi_o = 60°$

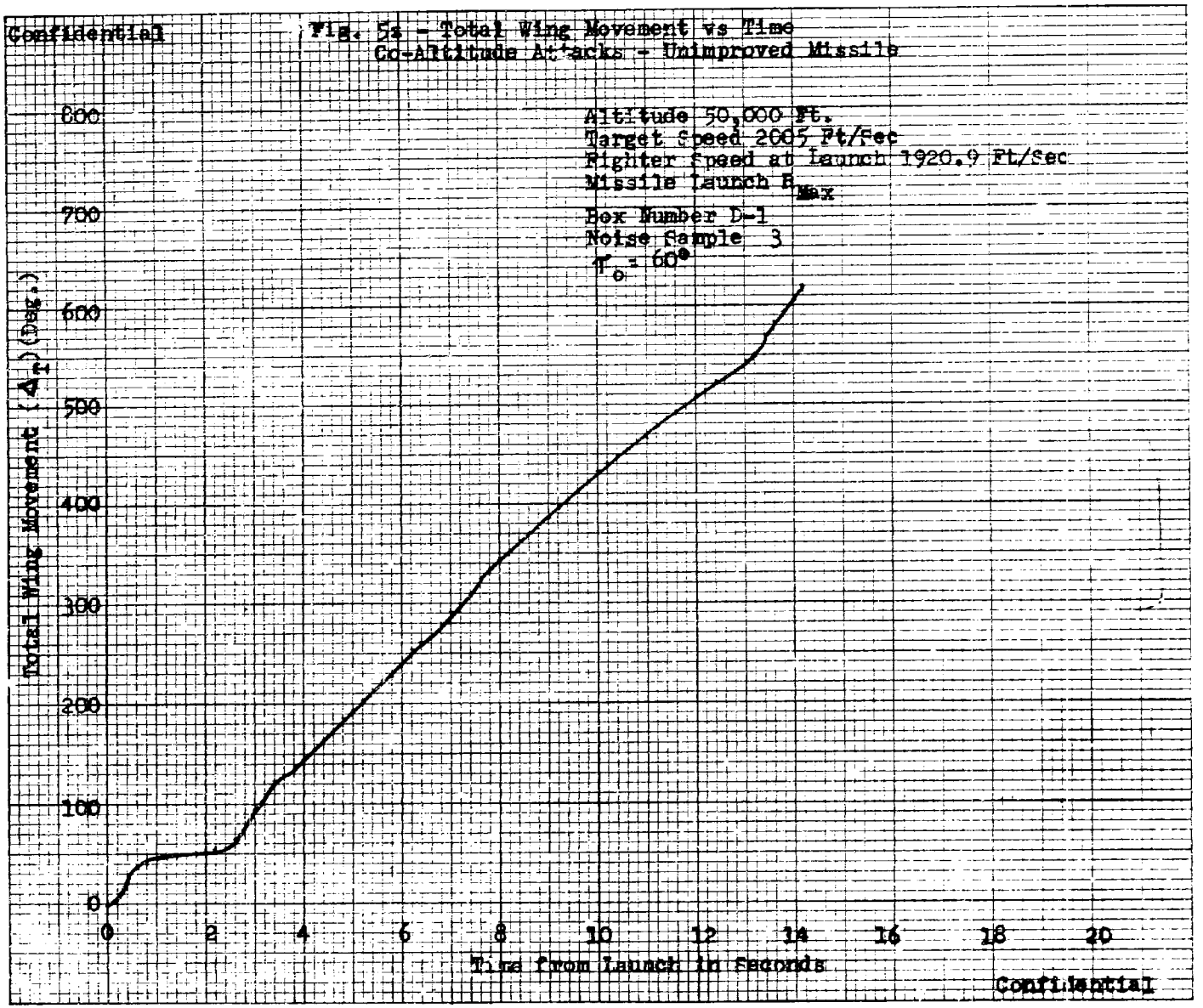

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Fig. 6a - Sparrow III Miss Distance - Pull-up Attacks
X-Y Miss Distance at the Target
$\gamma_o = 0°$, R_{max} Launch, Fighter Course - C-5
Unimproved Missile

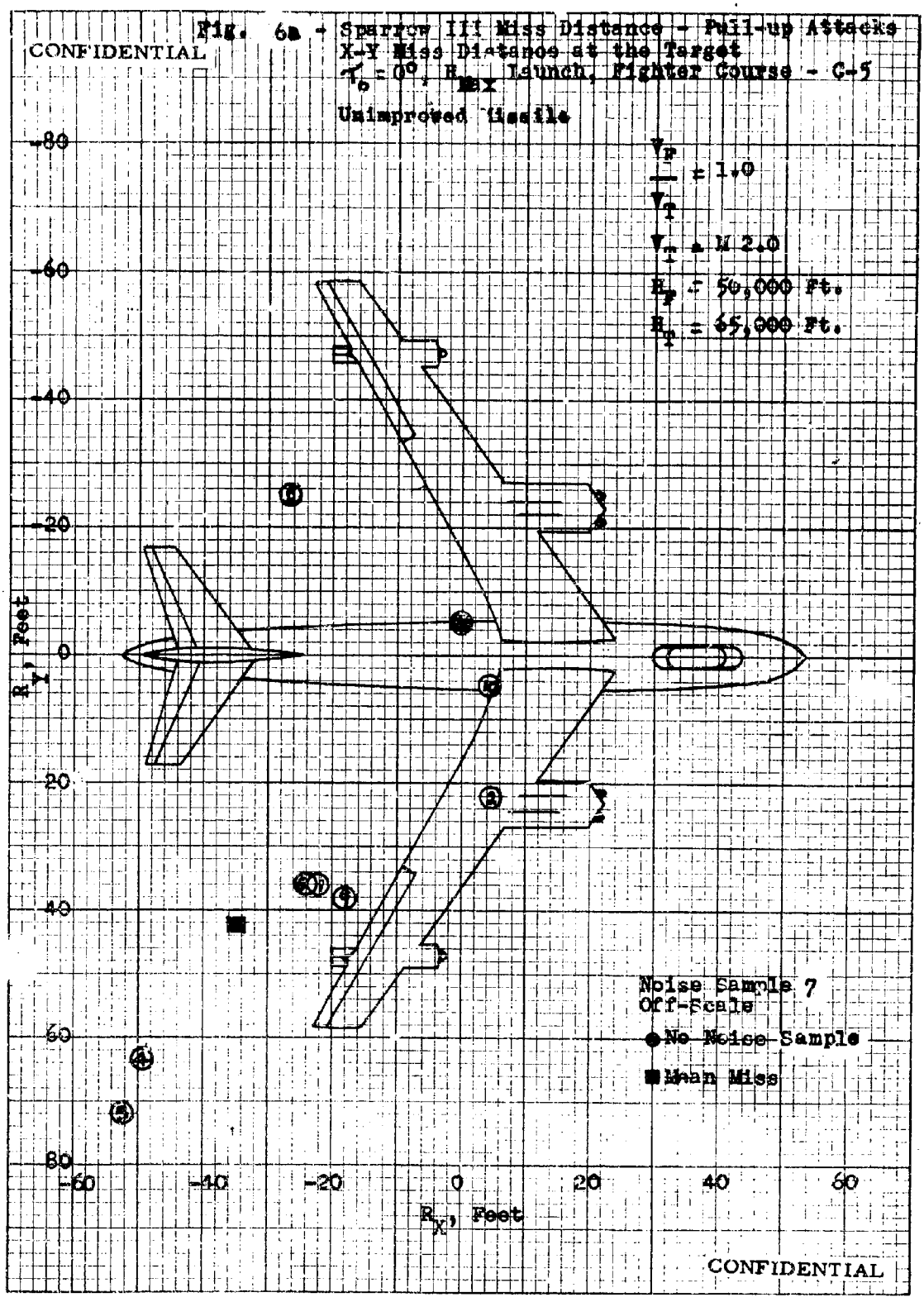

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Fig. 6b - Sparrow III Miss Distance - Pull-up Attacks
X-Z Miss Distance at the Target
$\gamma_o = 0^0$, R_{Max} Launch, Fighter Course - C-5
Unimproved Missile

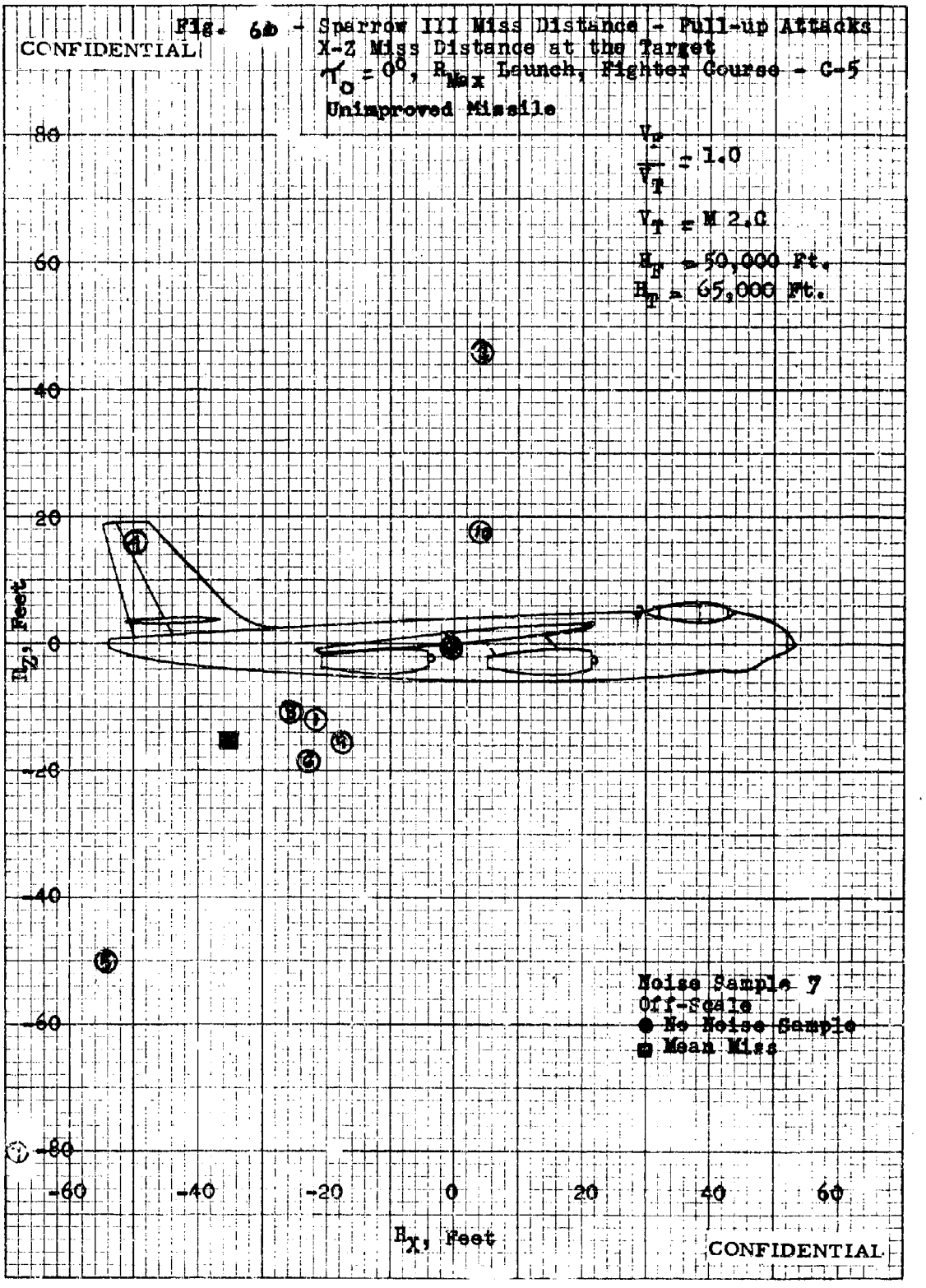

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Fig. 66 - Sparrow III Miss Distance - Pull-up Attacks
Y-2 Miss Distance at the Target
$\gamma_\phi = 0^0$, R_{Max} Launch, Fighter Course - C-5
Unimproved Missile

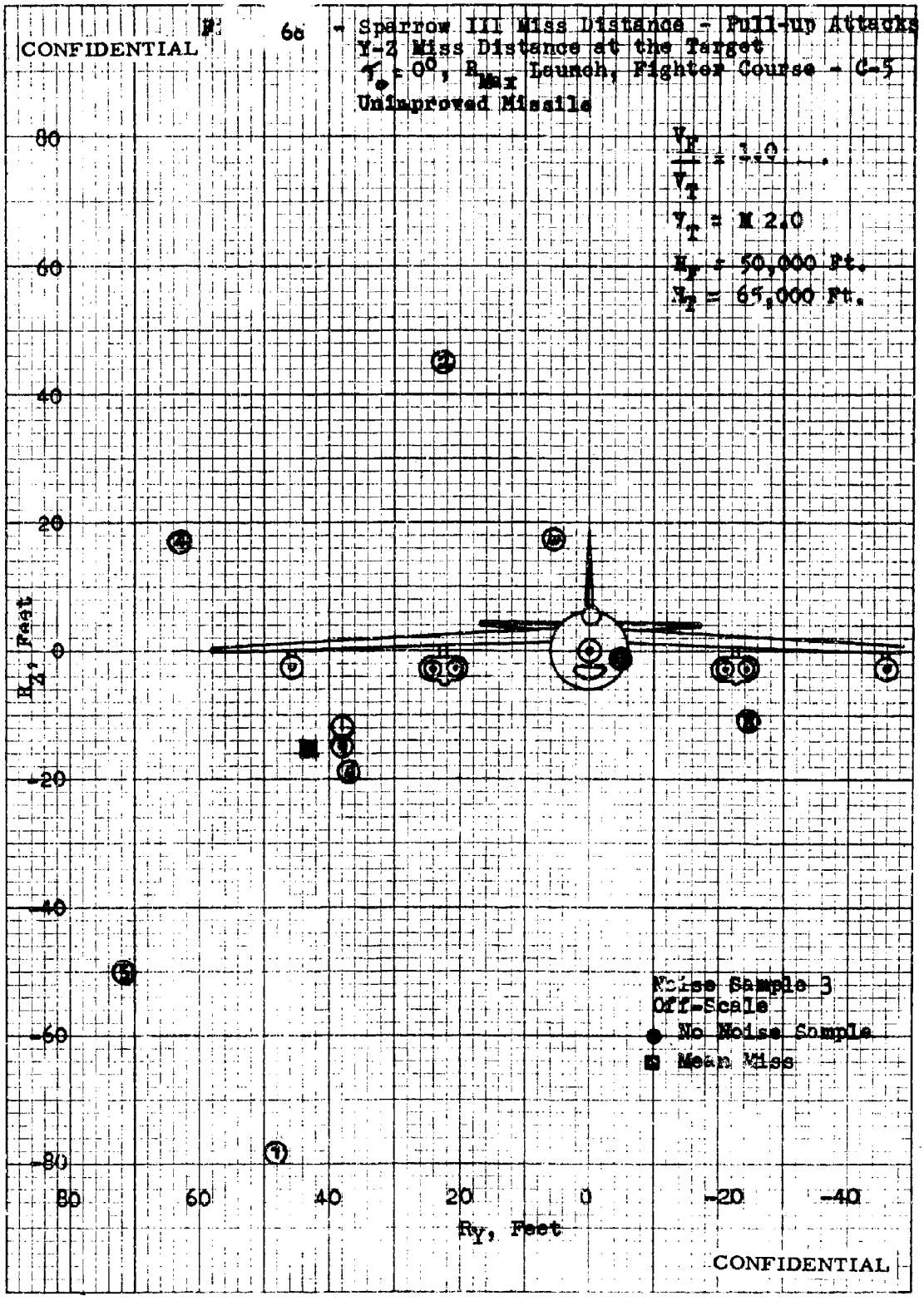


Fig. 6d - Fighter to Missile Range vs Time
Pull-up Attacks - Unimproved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 50,000 Ft.
Initial Fighter Speed 2005 Ft/Sec
Fighter Altitude at Launch 56,301 Ft.
Fighter Speed at Launch 1657.7 Ft/Sec
Missile Launch R_{max}
Box Number C-5
Noise Sample 5
$\gamma_o = 0°$

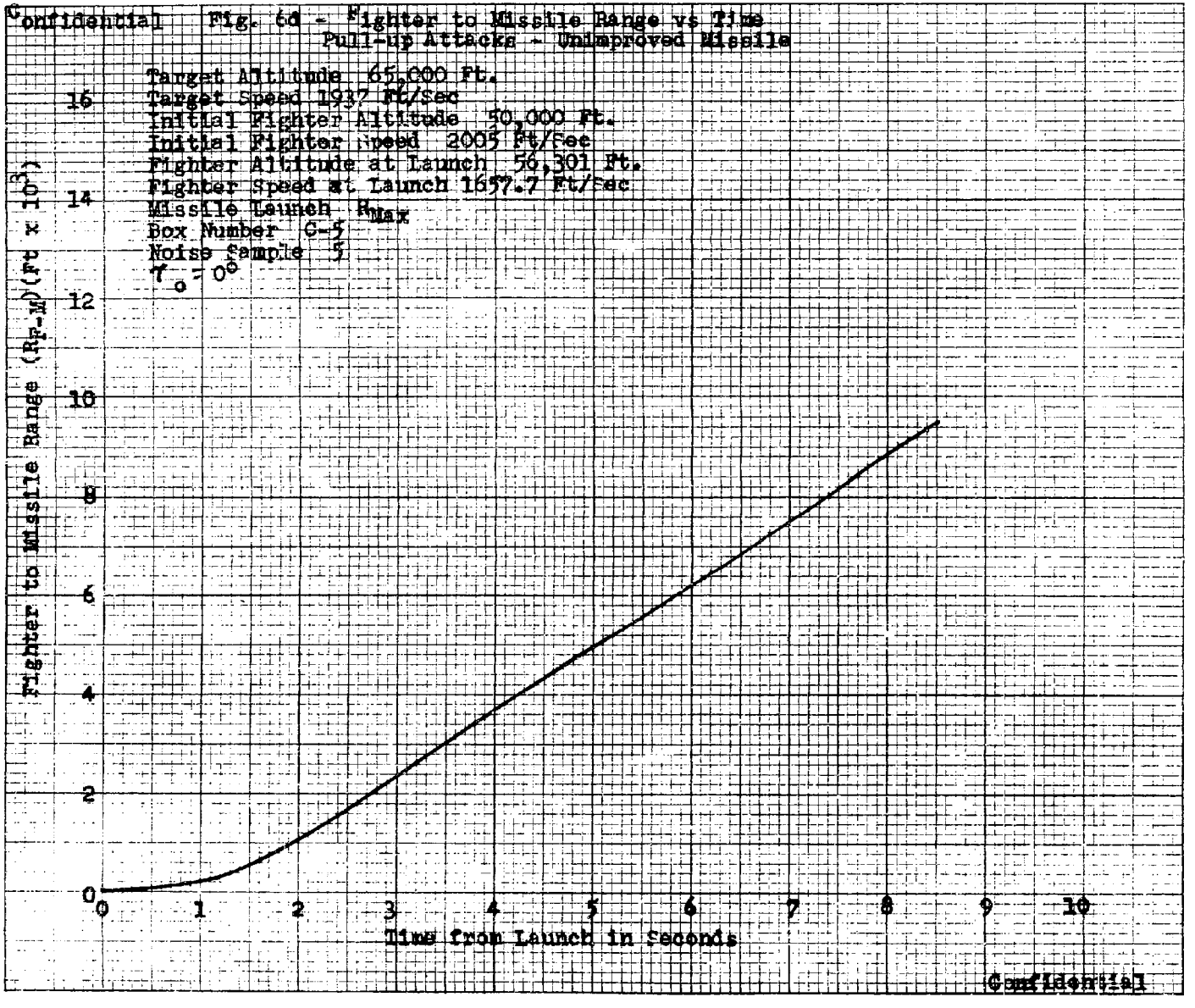
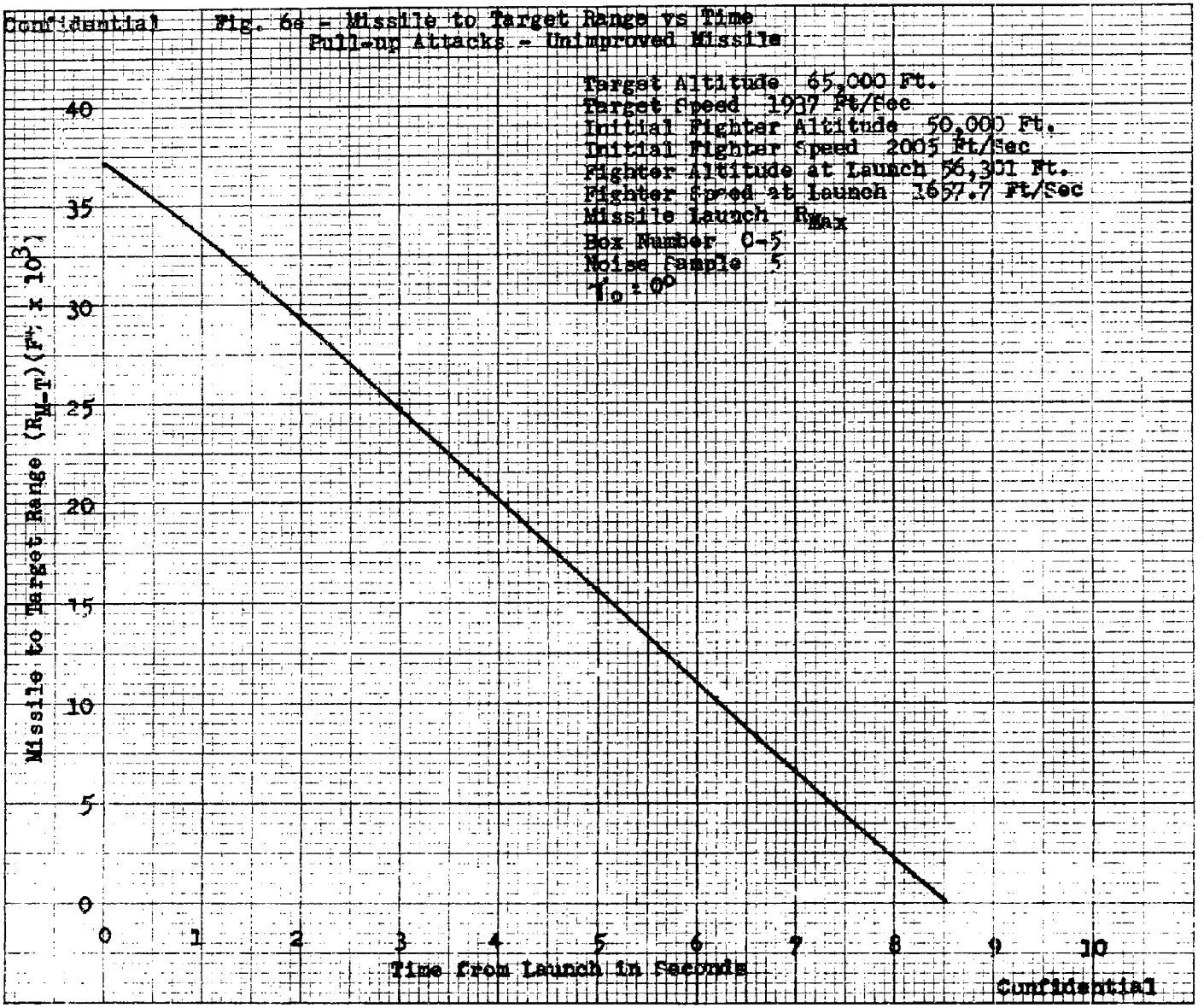


Fig. 6e - Missile to Target Range vs Time
Pull-up Attacks - Unimproved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 50,000 Ft.
Initial Fighter Speed 2005 Ft/Sec
Fighter Altitude at Launch 56,301 Ft.
Fighter Speed at Launch 1657.7 Ft/Sec
Missile Launch R_{Max}
Box Number 0-5
Noise Sample 5
γ_o : 0°



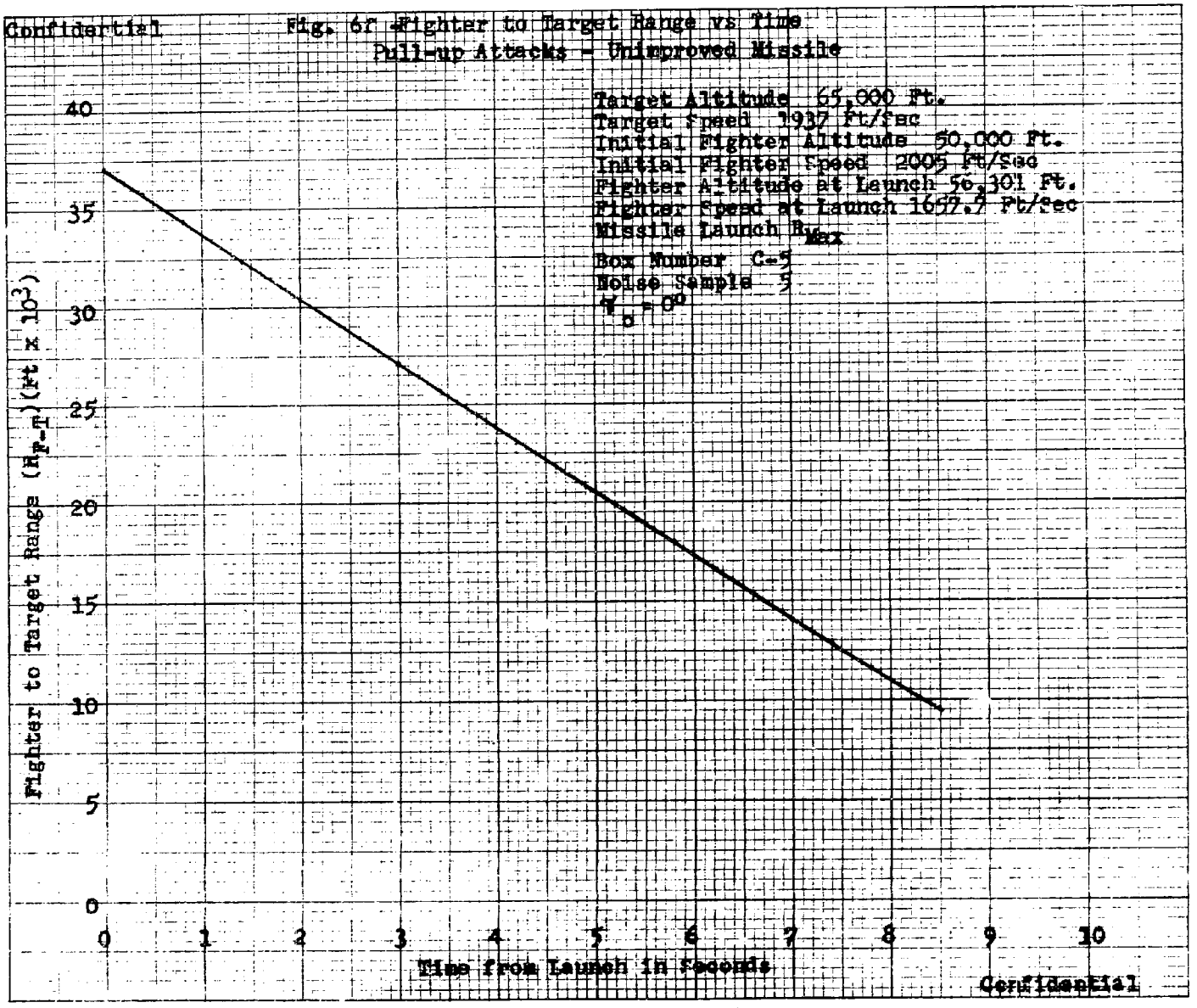


Fig. 6g- Fighter to Missile Range Rate vs Time
Pull-up Attacks - Unimproved Missile

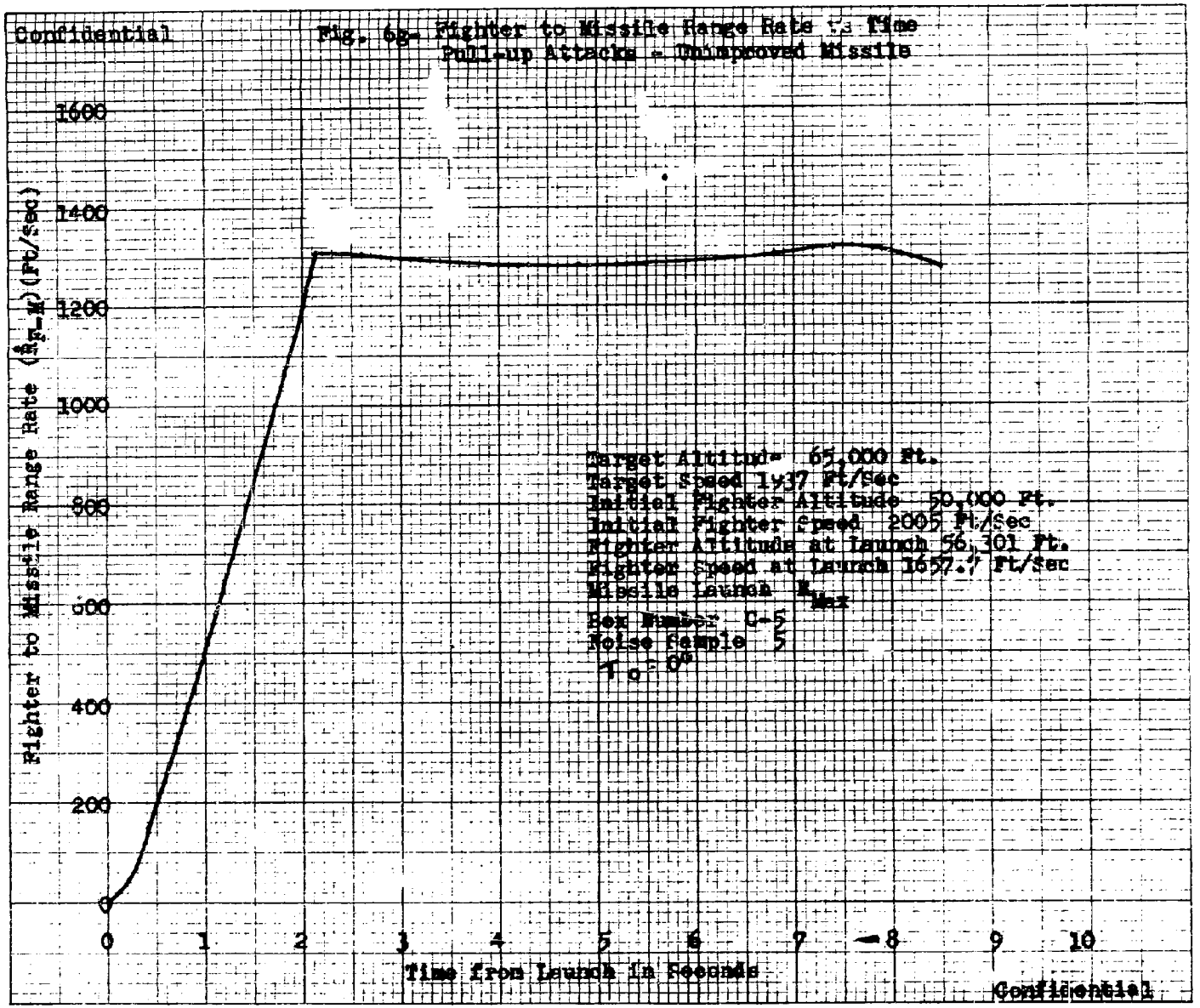


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Fig. 6h- Missile to Target Range Rate vs Time
Pull-up Attacks - Unimproved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 50,000 Ft.
Initial Fighter Speed 2005 Ft/Sec
Fighter Altitude at Launch 56,301 Ft.
Fighter Speed at Launch 1657.7 Ft/Sec
Missile Launch R_{Max}

Box Number C-5
Noise Sample 5
$\gamma_o = 0^o$

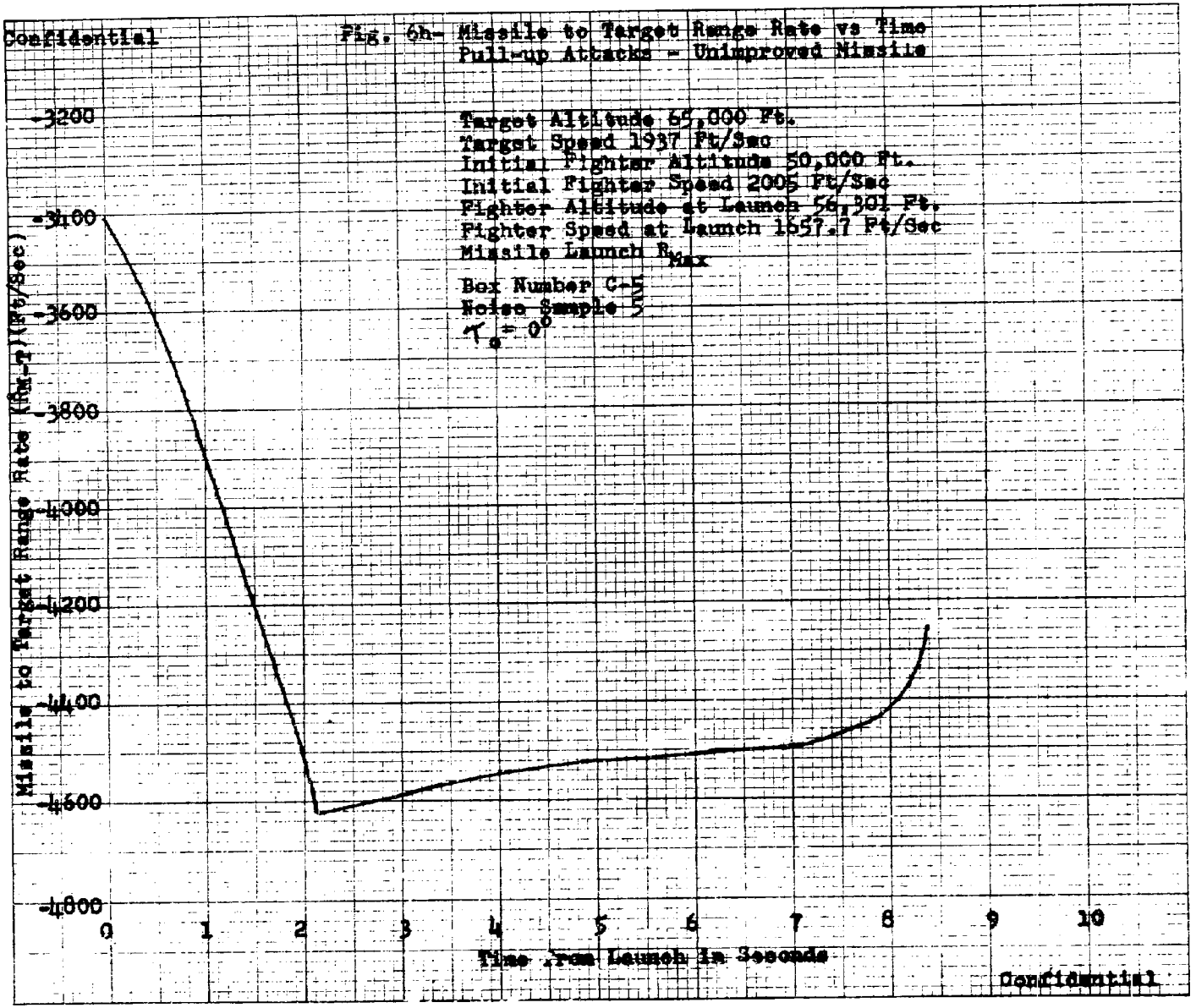

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Fig. 61-Fighter to Target Range Rate vs Time
Pull-up Attacks - Improved Missile

Target Altitude 65,000 Ft.
Target Speed 937 Ft/Sec
Initial Fighter Altitude 30,000 Ft.
Initial Fighter Speed 2005 Ft/Sec
Fighter Altitude at Launch 56,301 Ft.
Fighter Speed at Launch 1657.7 Ft/Sec
Missile Launch r_{Max}

Box Number C-5
Noise Sample 5
$\gamma_o = 0^o$

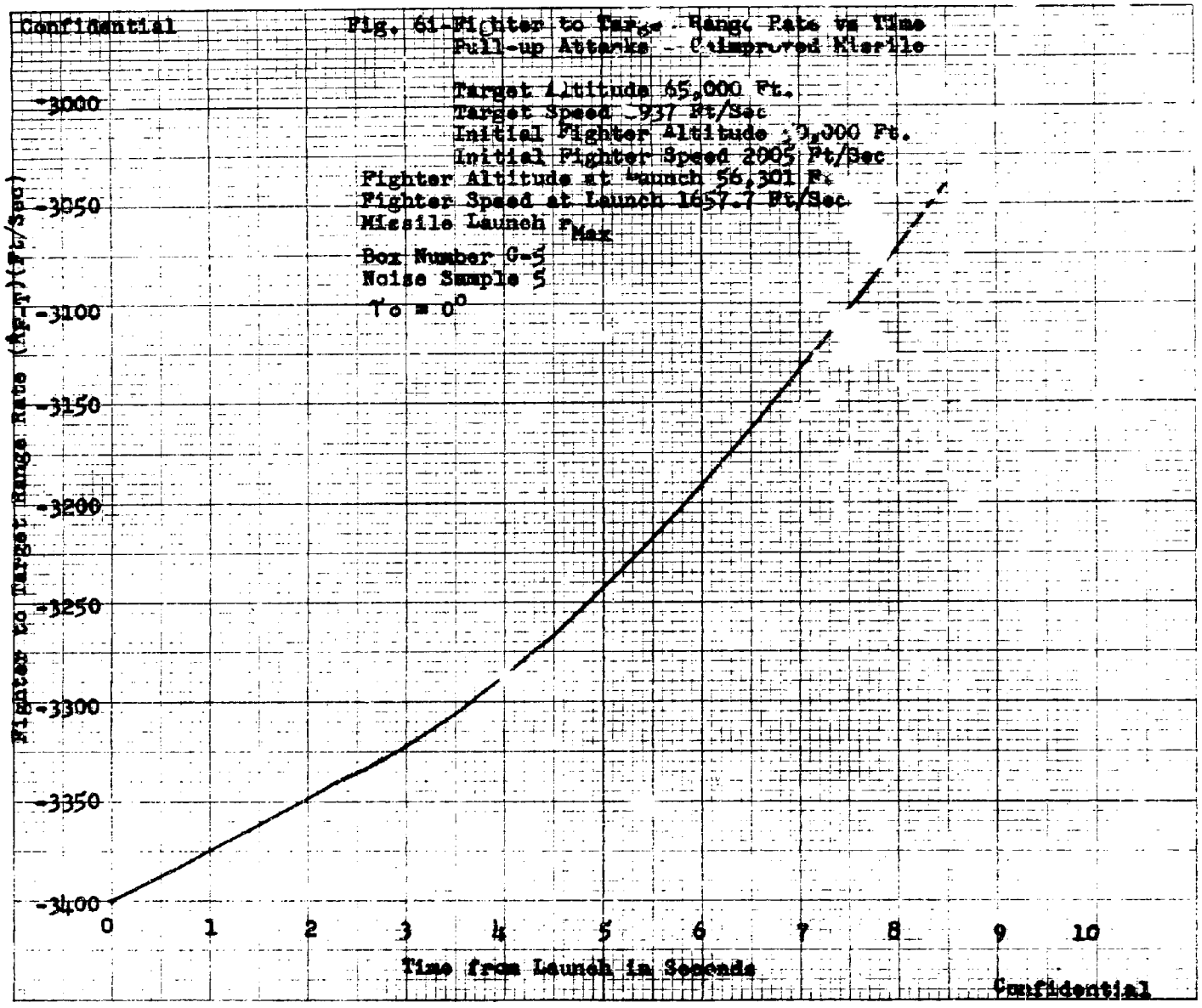

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Fig. 6j - Antenna Azimuth Gimbal Angle of Missile vs Time
Pull-up Attacks - Unimproved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 50,000 Ft.
Initial Fighter Speed 2005 Ft/Sec
Fighter Altitude at Launch 56,301 Ft.
Fighter Speed at Launch 1657.7 Ft/Sec
Missile Launch R_{Max}
Box Number C-5
Noise Sample 5
$\gamma_o = 0°$

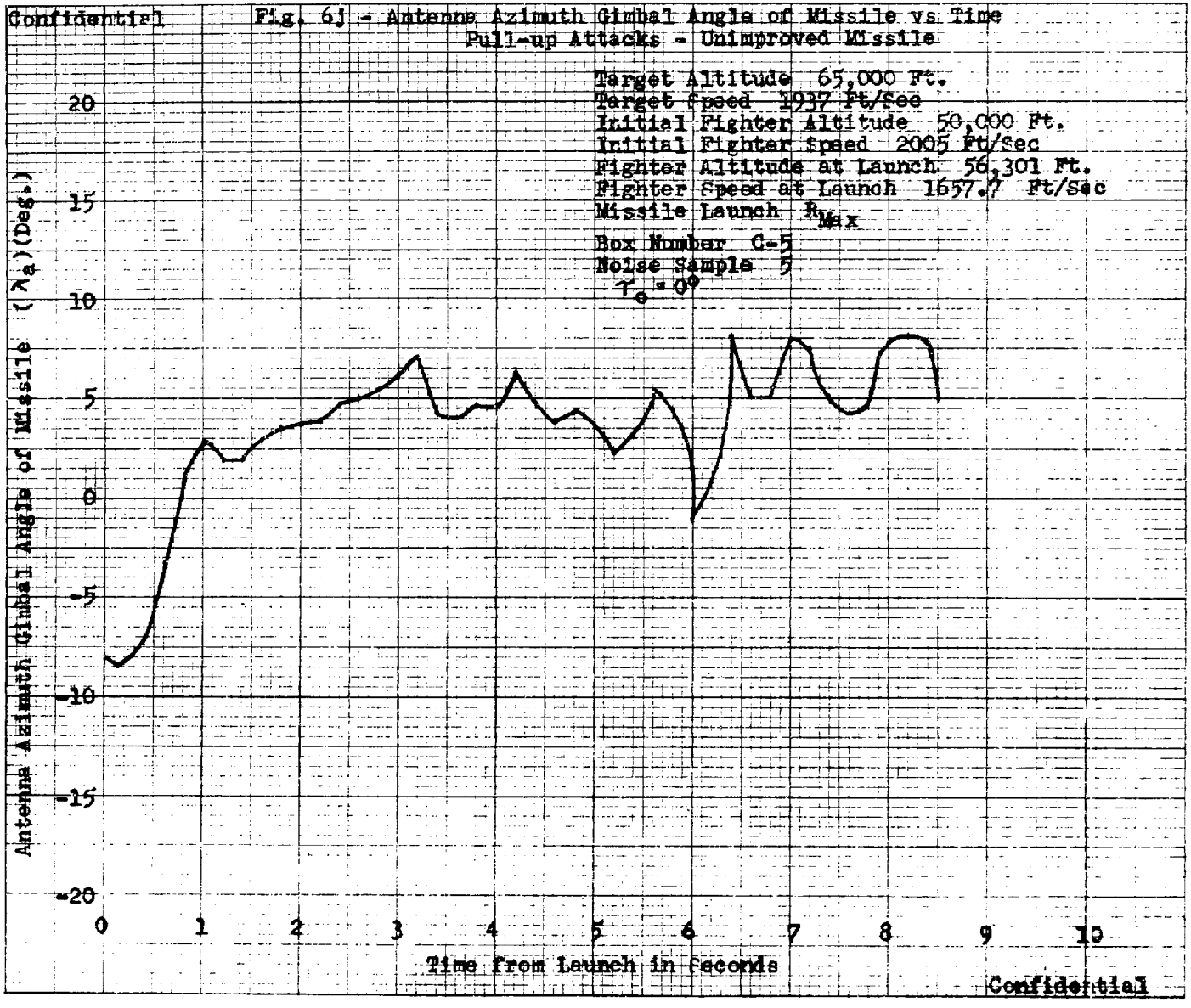

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Fig. 6K -Antenna Elevation Gimbal Angle of Missile vs Time
Pull-up Attacks - Unimproved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 50,000 Ft.
Initial Fighter Speed 2005 Ft/Sec
Fighter Altitude at Launch 56,301 Ft.
Fighter Speed at Launch 1657.7 Ft/Sec
Missile Launch R_{Max}
Box Number C-5
Noise Sample 5
$T_o = 0^o$

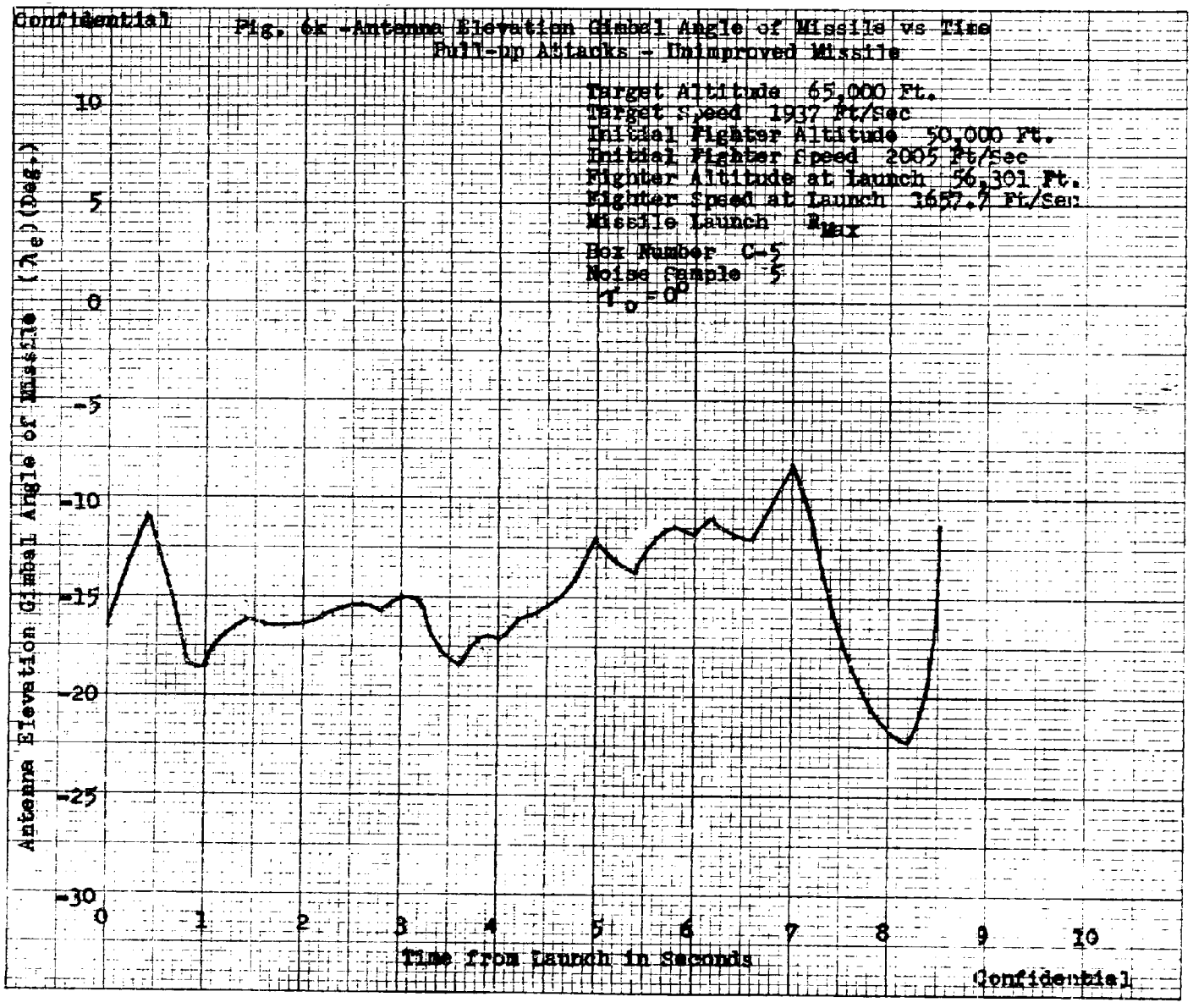

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Fig. 6-1 - Missile Lead Angle vs Time
Pull-up Attacks - Unimproved Missile

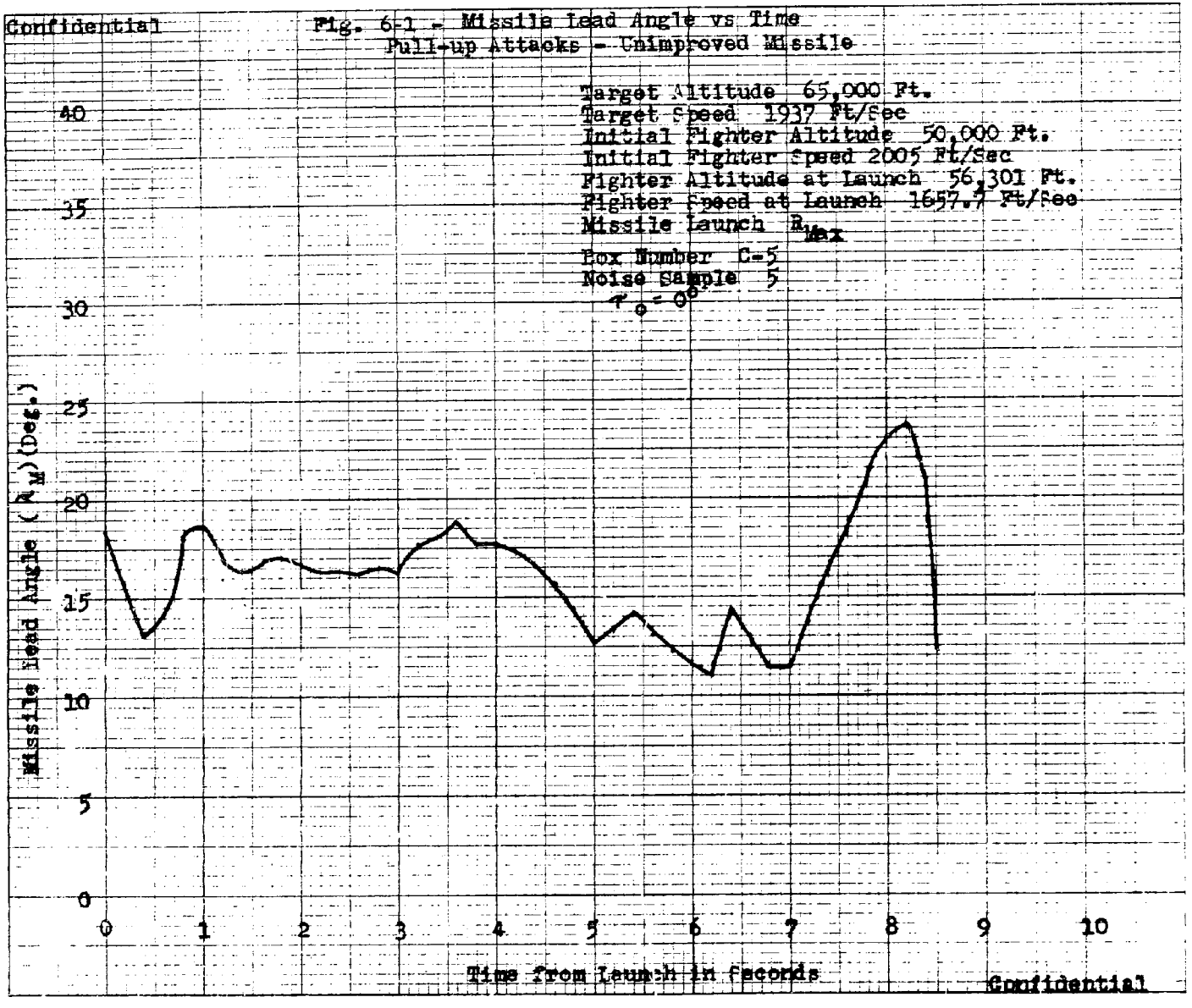

Fig. 6a - Azimuth Line of Sight Rate of Missile vs Time
Pull-up Attacks - Unimproved Missile

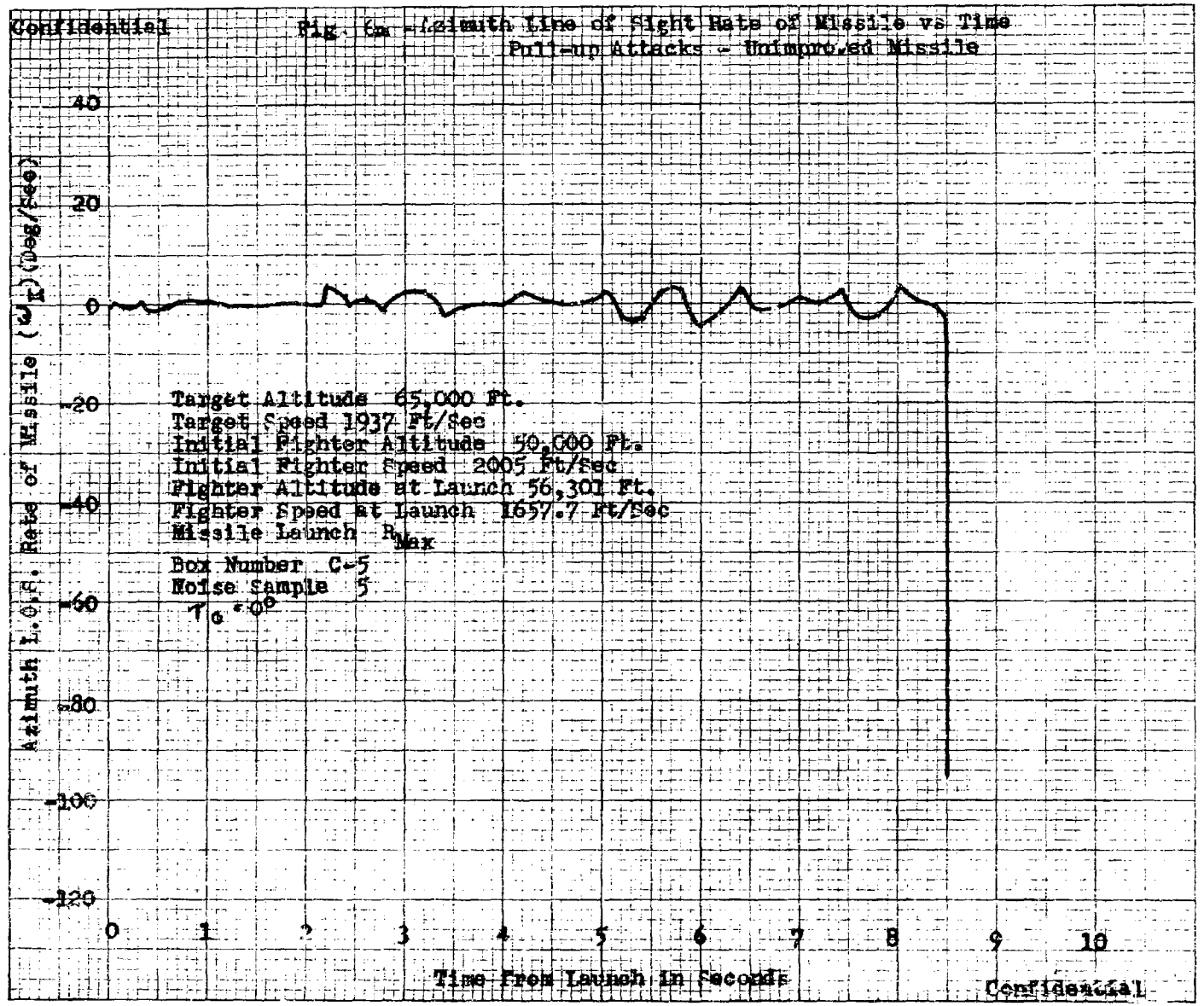

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Fig. 6n - Elevation Line of Sight Rate of Missile vs Time
Pull-up Attacks - Unimproved Missile

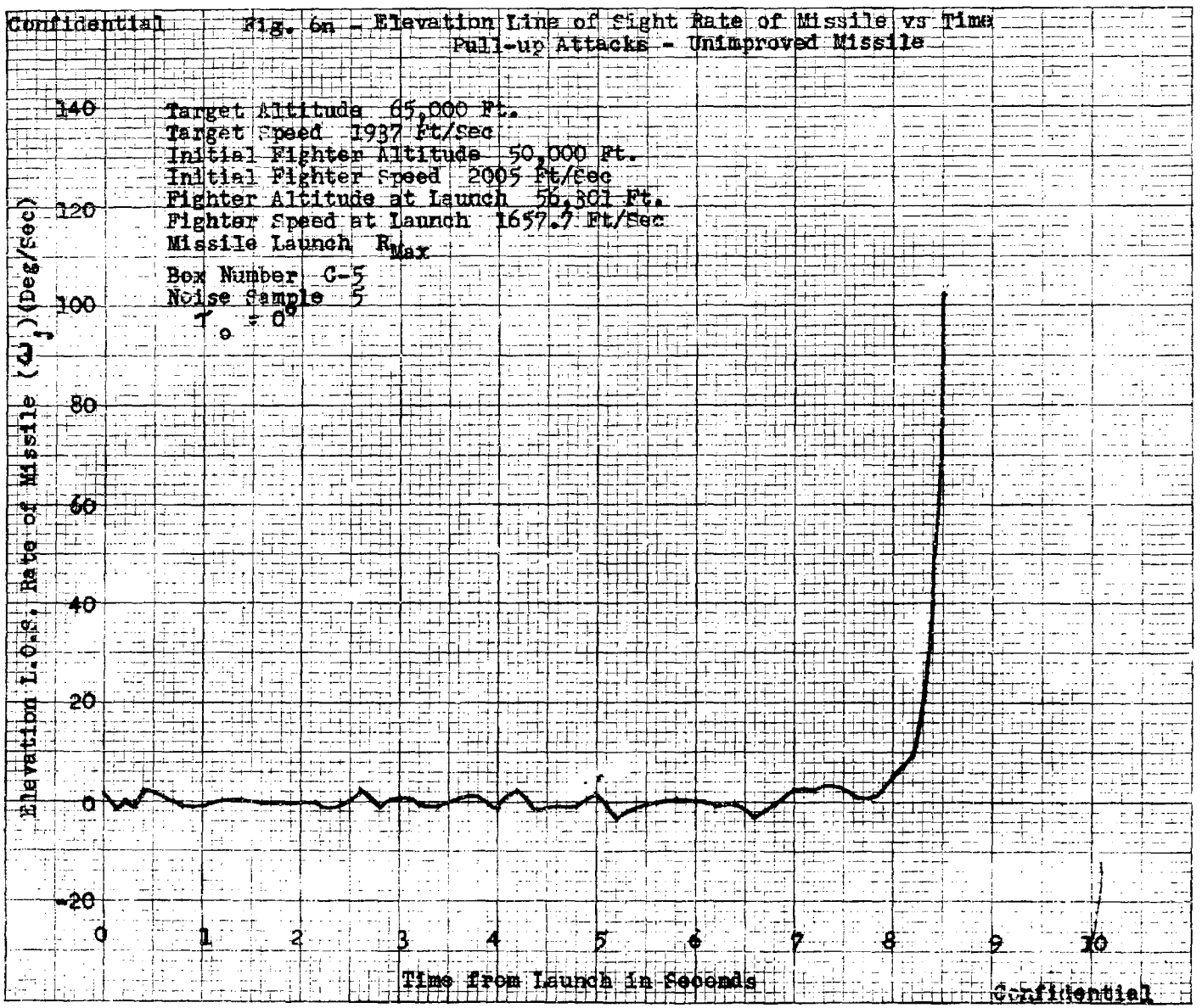

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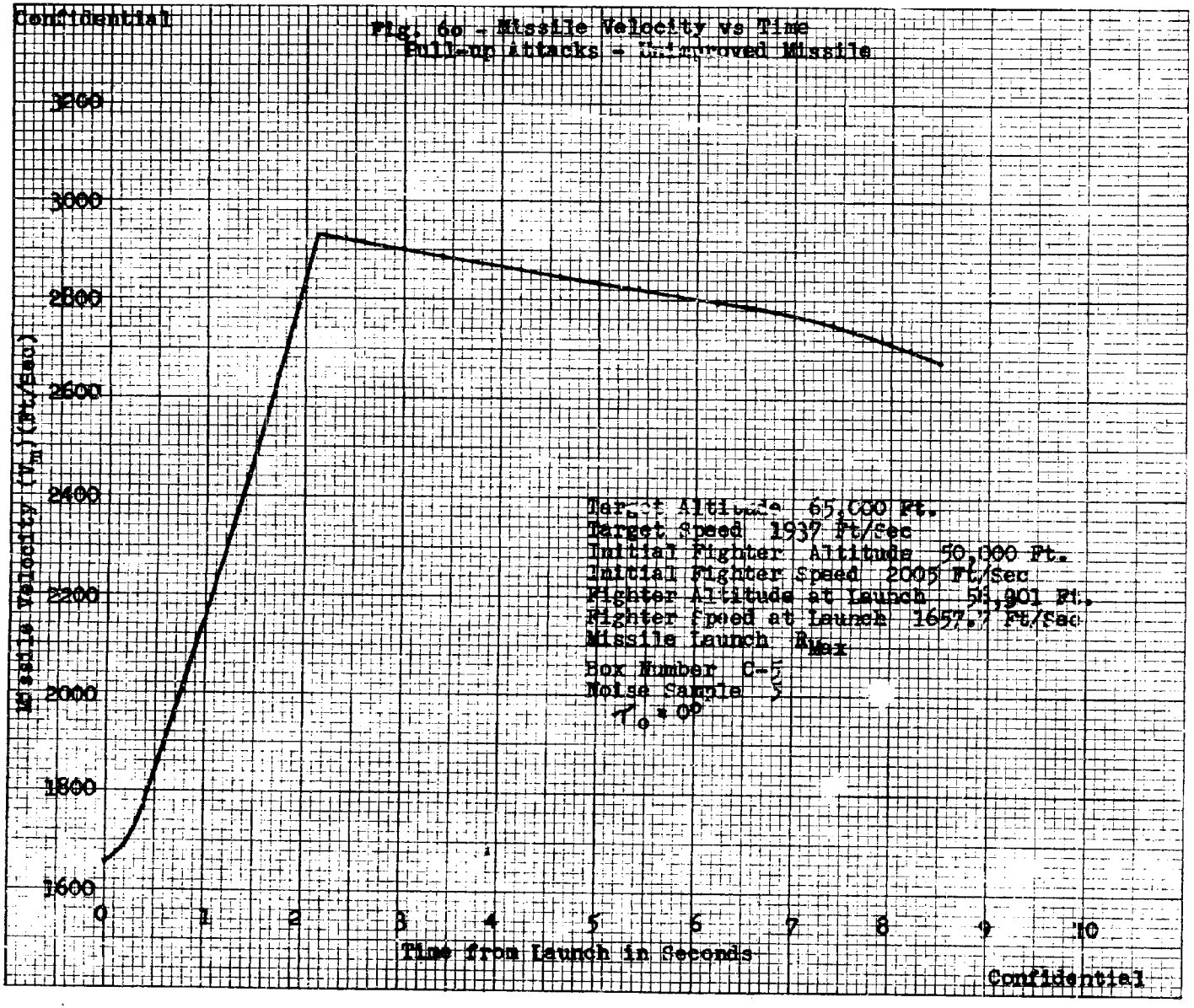
Fig. 6o - Missile Velocity vs Time
Pull-up Attacks - Improved Missile



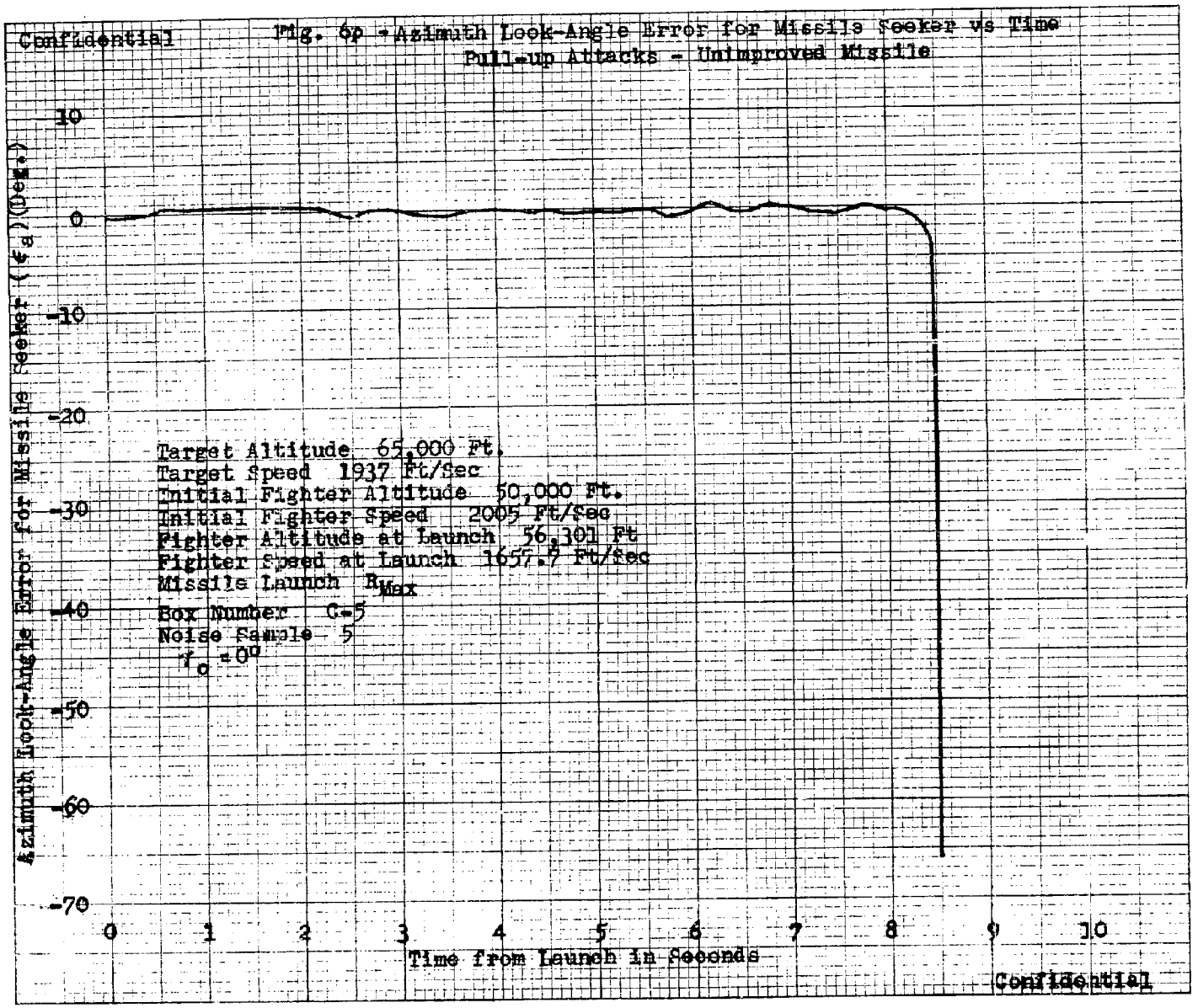


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Fig. 6q - Elevation Look-Angle Error for Missile Seeker vs Time
Pull-up Attacks - Unimproved Missile

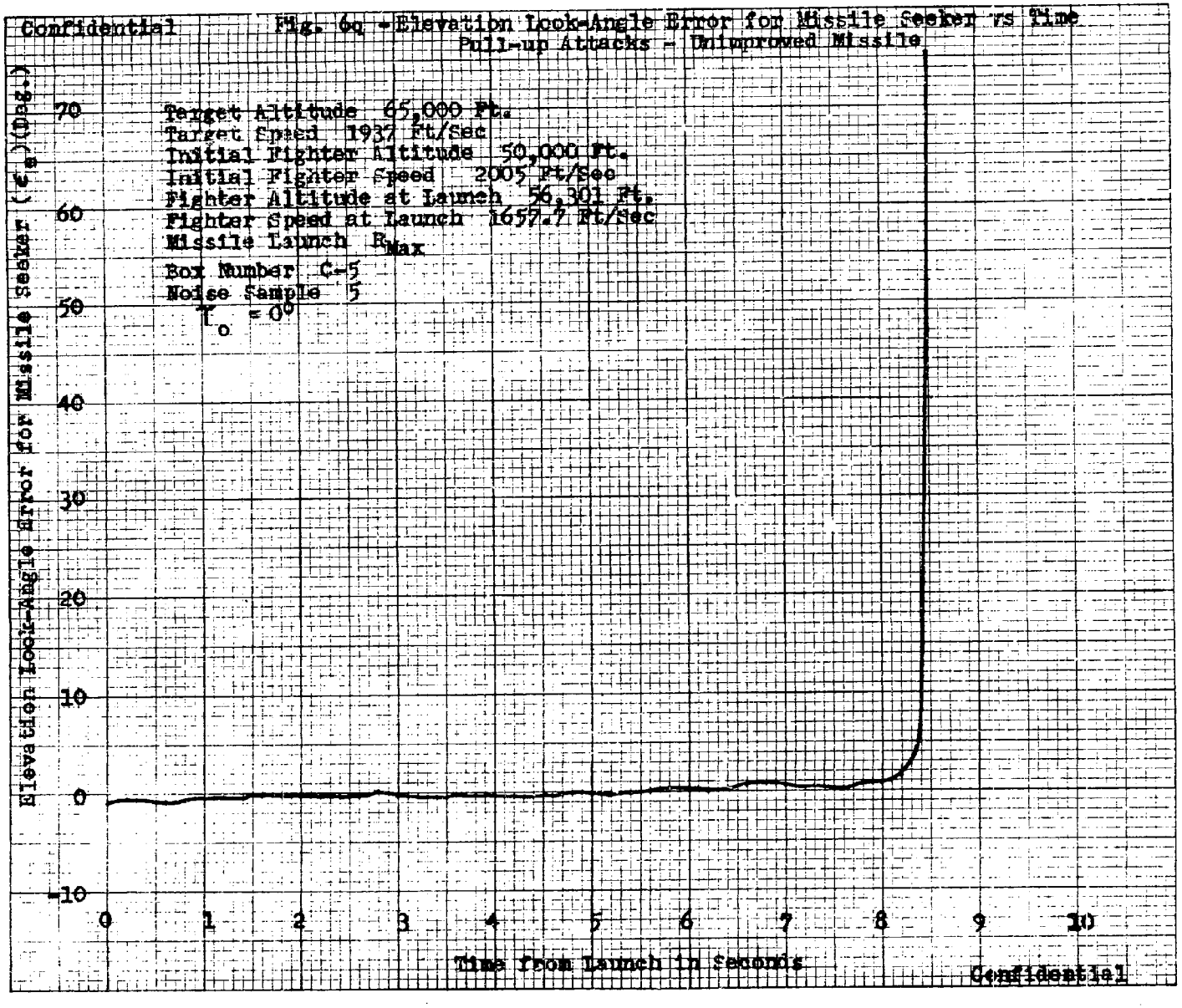

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Fig. 6r - Missile Angle of Attack vs Time
Pull-up Attacks - Unimproved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 50,000 Ft.
Initial Fighter Speed 2005 Ft/Sec
Fighter Altitude at Launch 56,301 Ft.
Fighter Speed at Launch 1657.7 Ft/Sec
Missile Launch R_{Max}
Box Number C-5
Noise Sample 5
$\gamma_o = 0°$

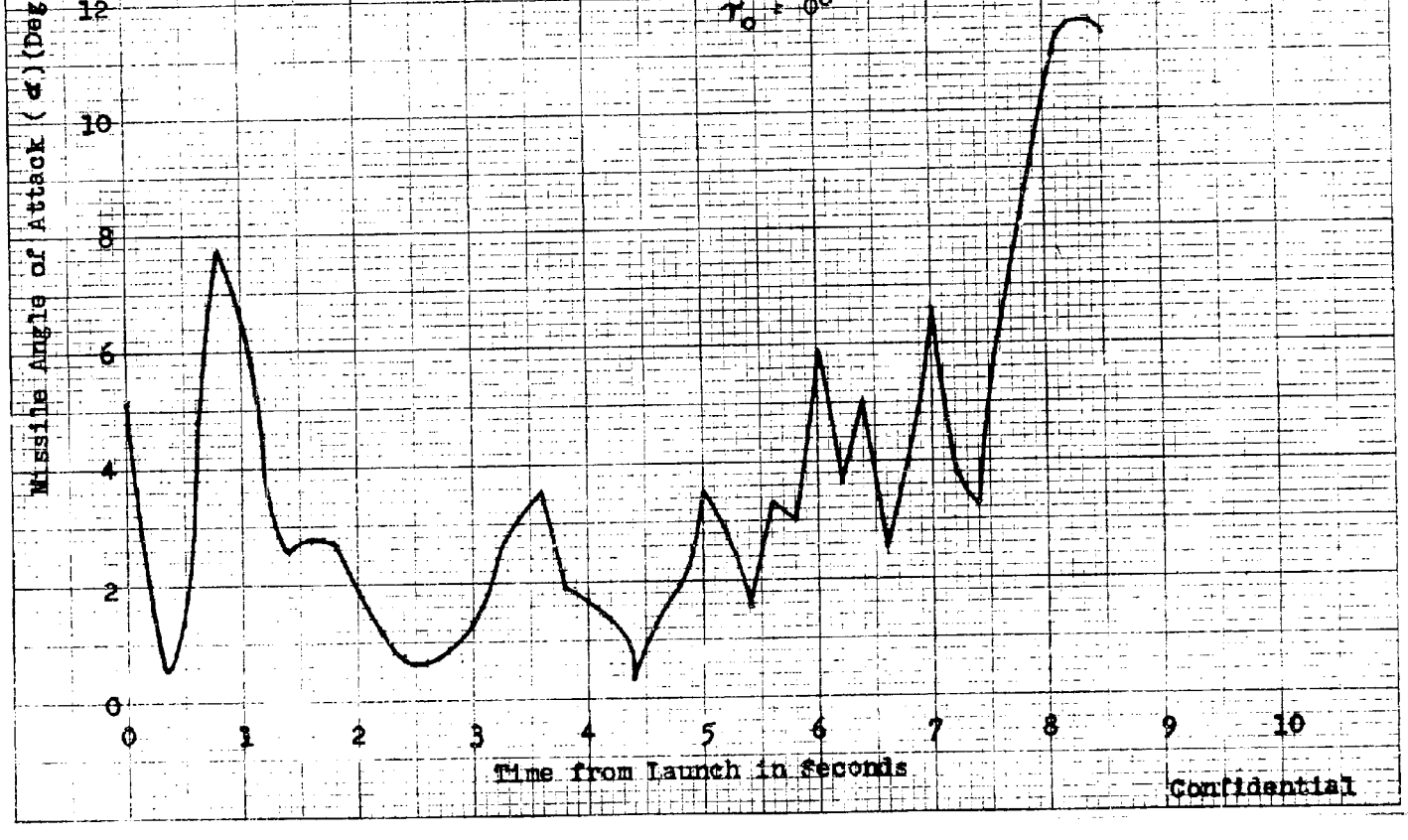

Fig. 54 - Missile and Fighter Roll Angle vs Time
Pull-up Attacks - Unimproved Missile

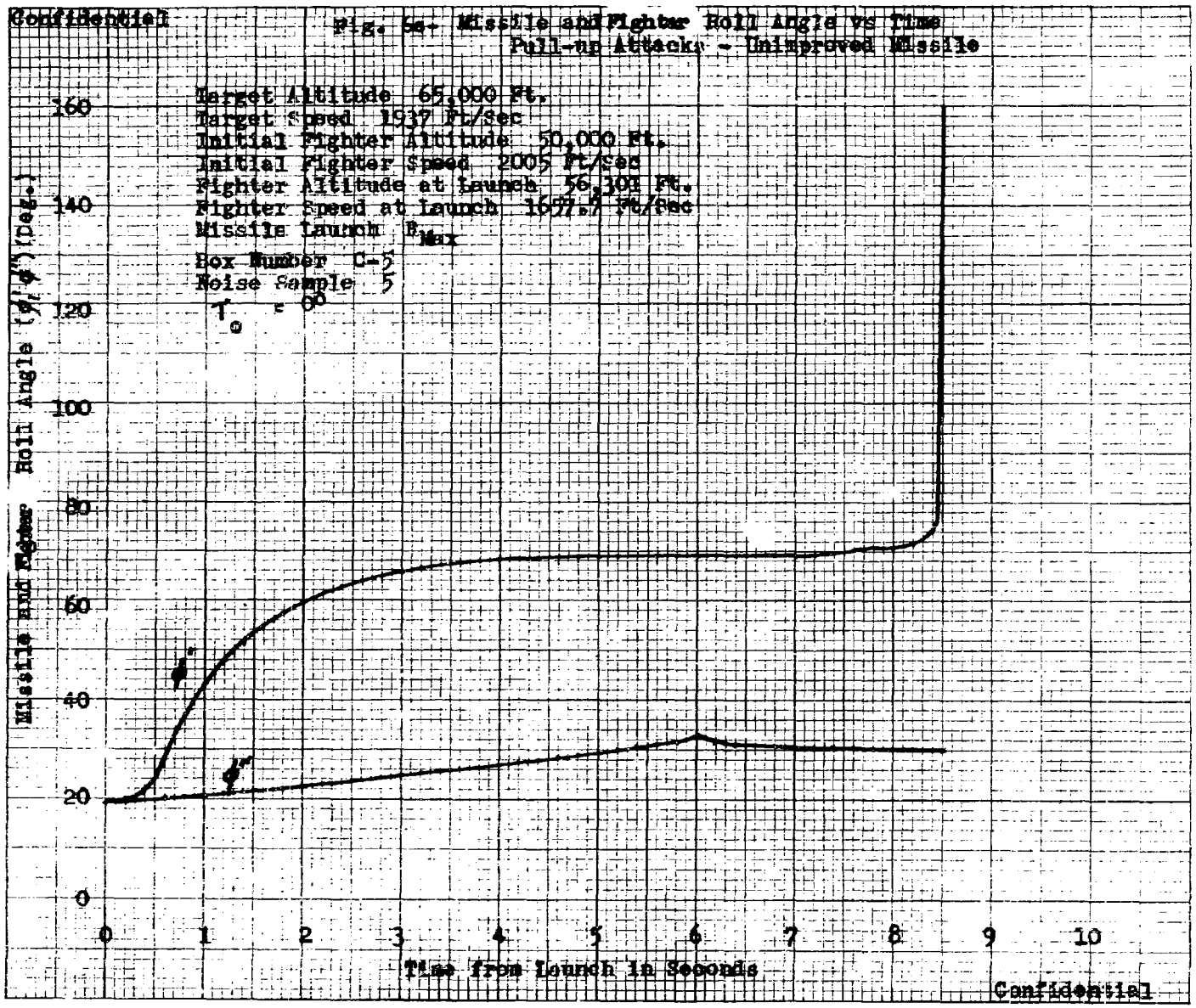

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Fig. 6t-Commanded Elevation G's vs Time
Pull-up Attacks - Unimproved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 50,000 Ft.
Initial Fighter Speed 2005 Ft/Sec
Fighter Altitude at Launch 56,301 Ft.
Fighter Speed at Launch 1657.7 Ft/Sec
Missile Launch R_{Max}
Box Number C-5
Noise Sample 5
$\gamma_o = 0^o$

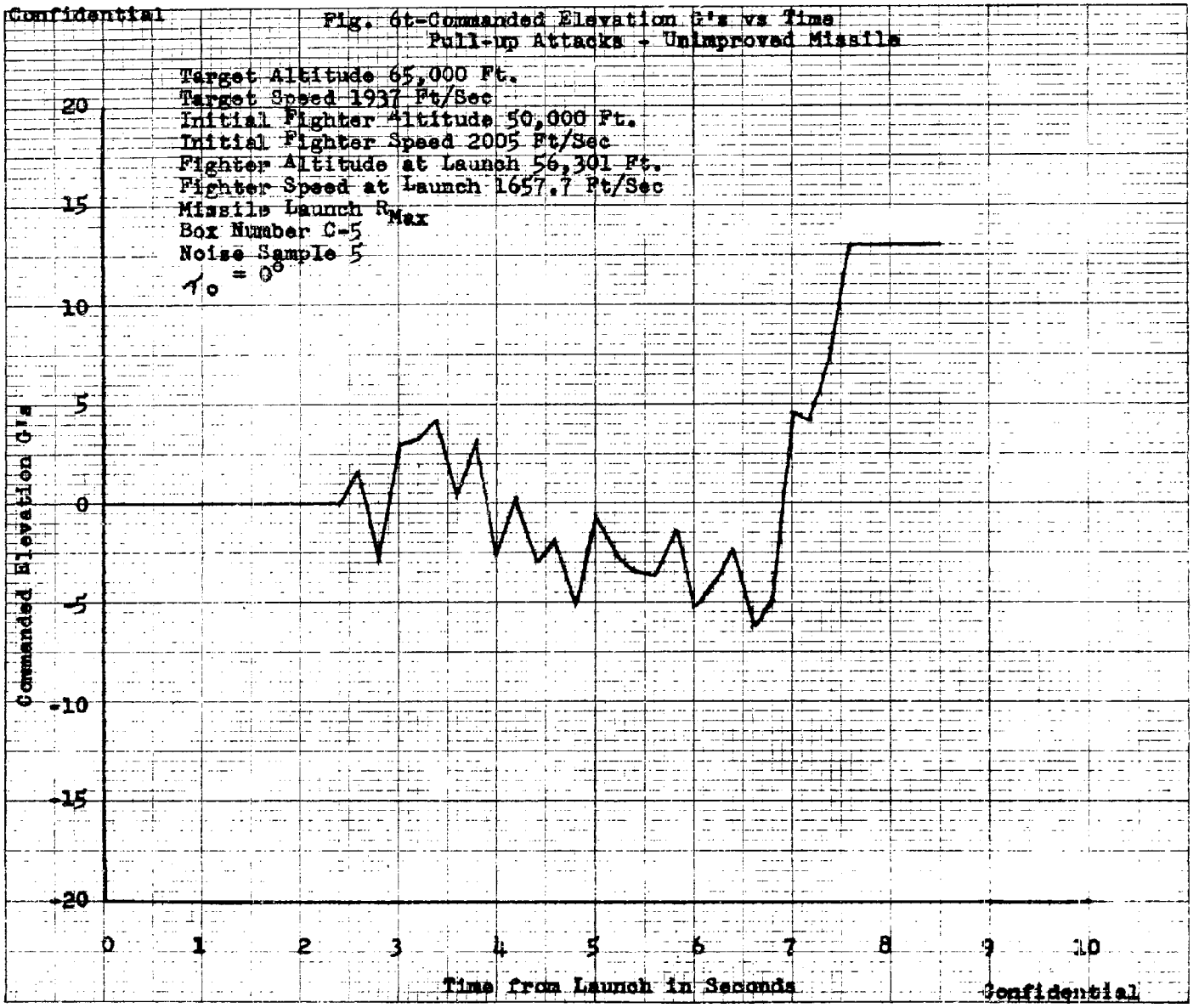

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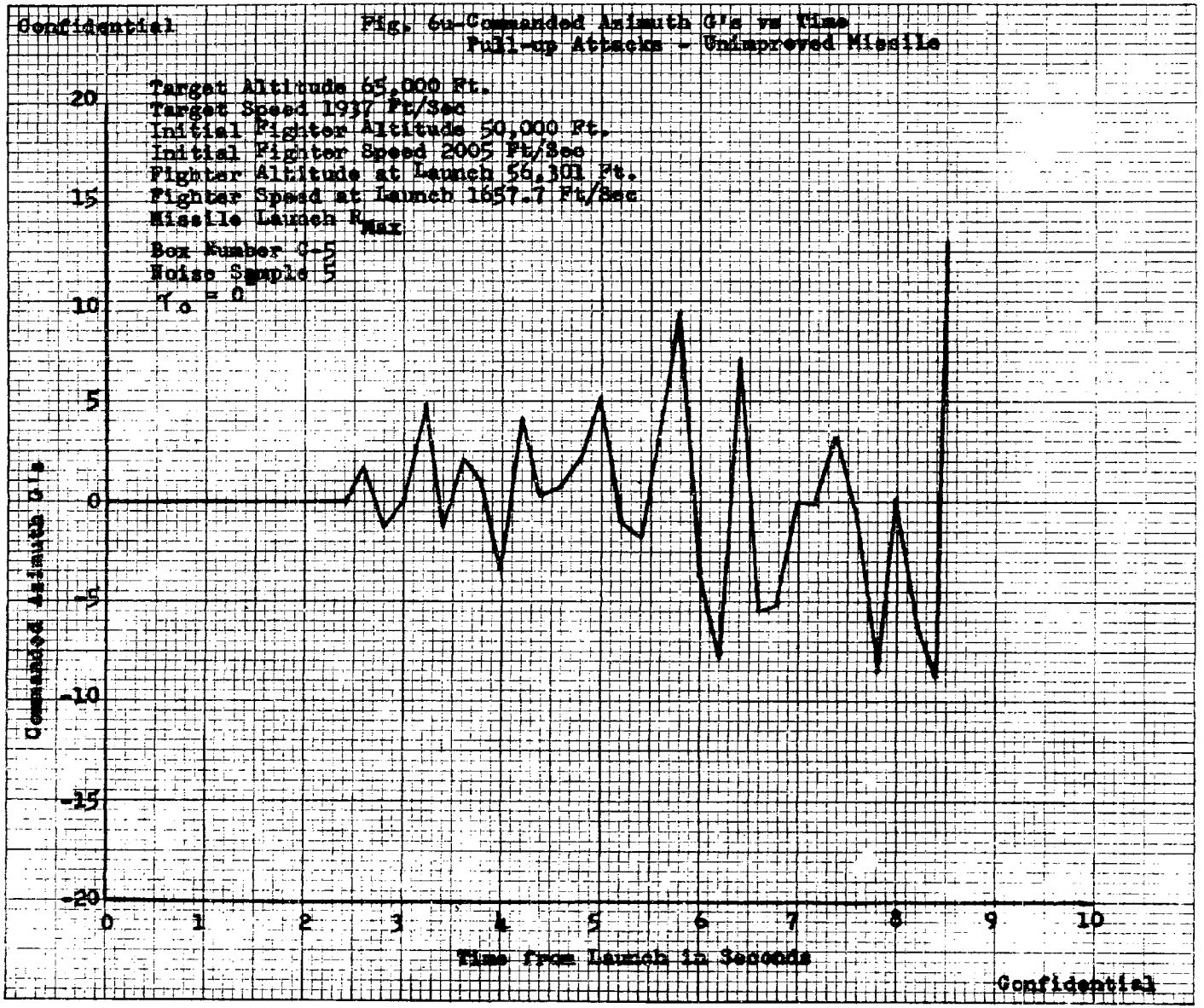
Fig. 6a-Commanded Azimuth G's vs Time
Pull-up Attacks - Unimproved Missile



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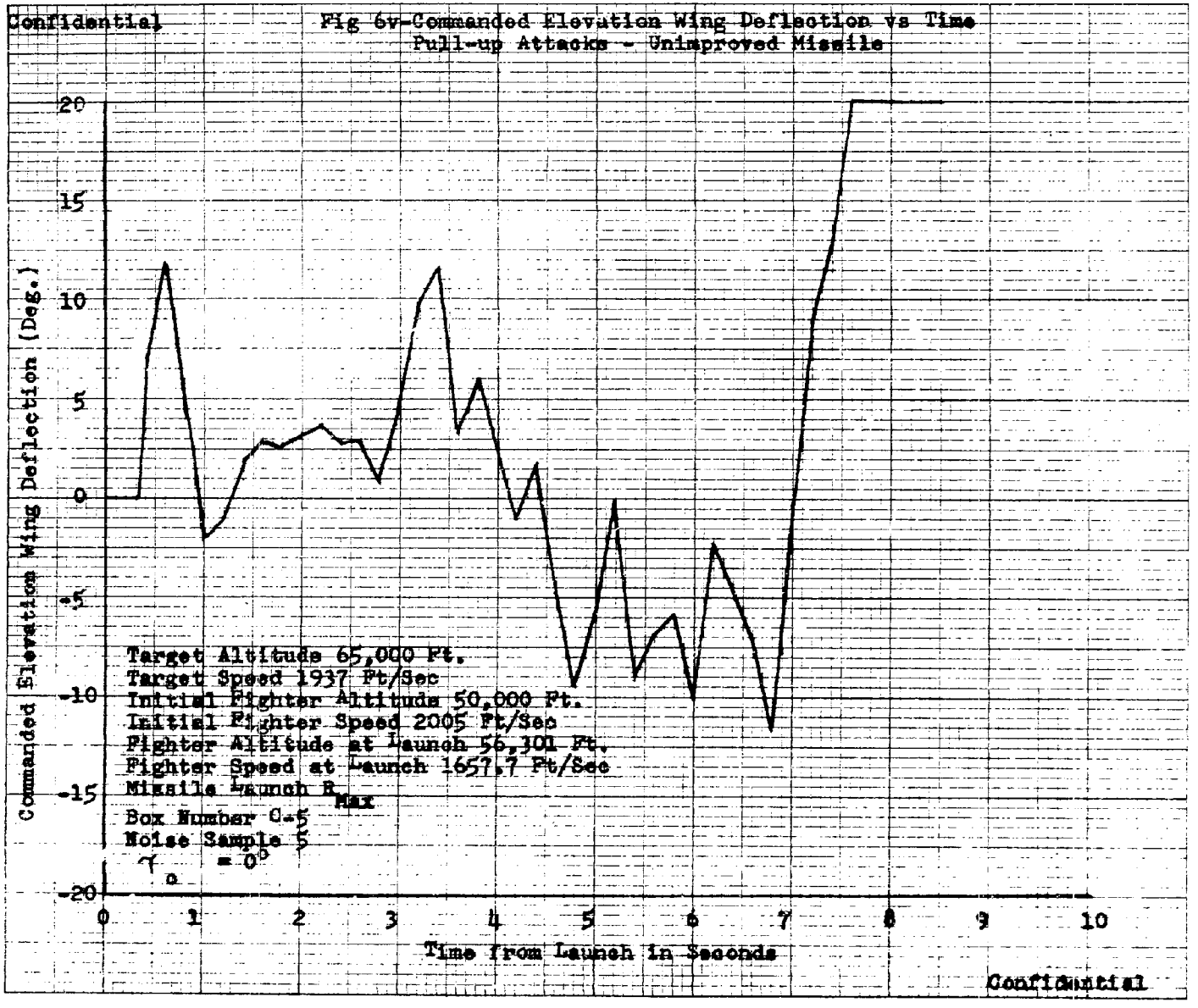

Fig. 6w-Commanded Azimuth Wing Deflection vs Time
Full-up Attacks - Unimproved Missile

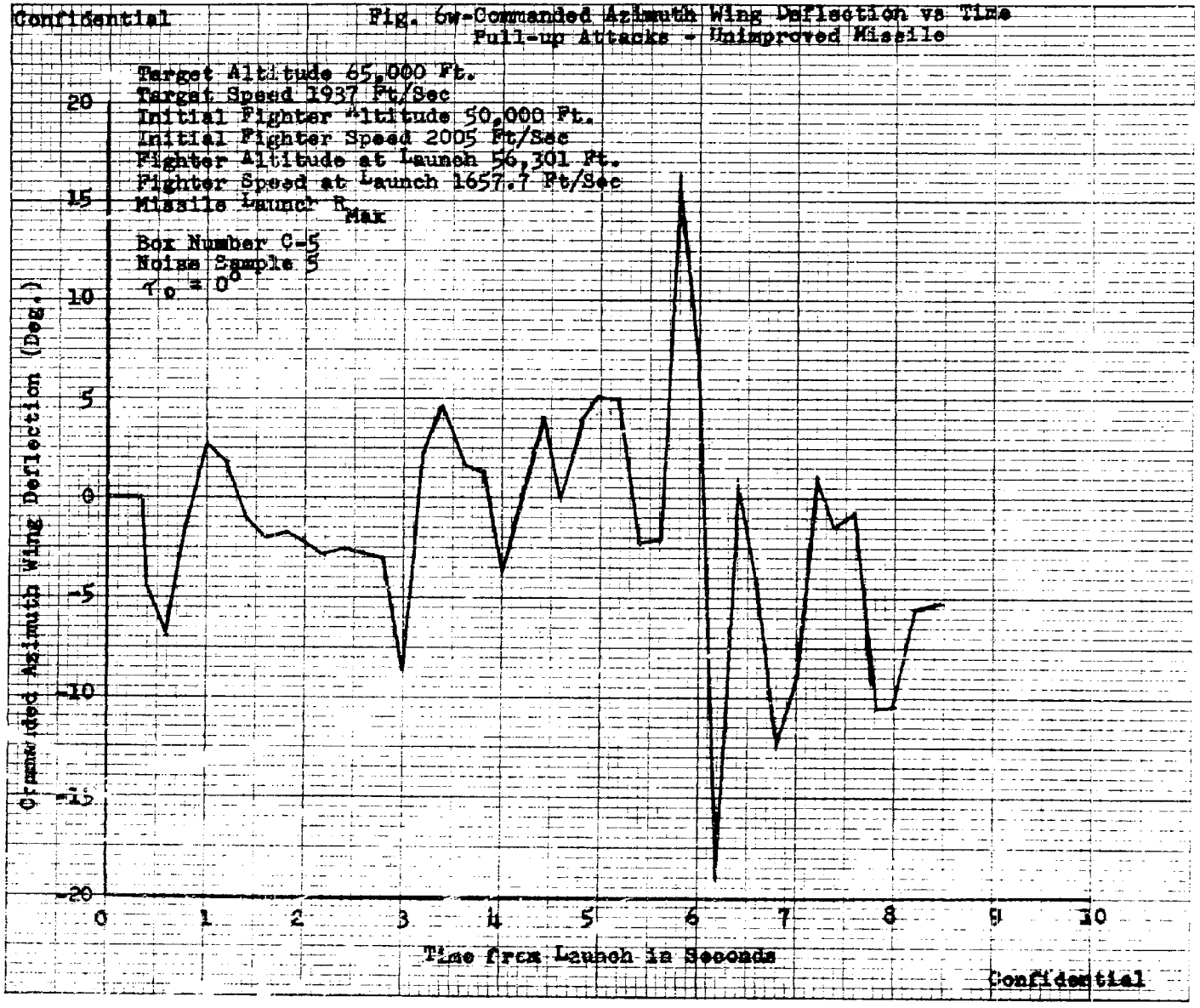

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Fig. 6x - Deflection of Missile Pitch Wings vs Time
Pull-up Attacks - Unimproved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/sec
Initial Fighter Altitude 50,000 Ft.
Initial Fighter Speed 2005 Ft/sec
Fighter Altitude at Launch 56,301 Ft.
Fighter Speed at Launch 1657.7 Ft/sec
Missile Launch R_{Max}
Box Number C-5
Noise Sample 5
$T_o = 0°$

Deflection of Missile Pitch Wings (Δ_p)(Deg.)

25
20
15
10
5
0
-5
-10
-15

0 1 2 3 4 5 6 7 8 9 10

Time from Launch in Seconds

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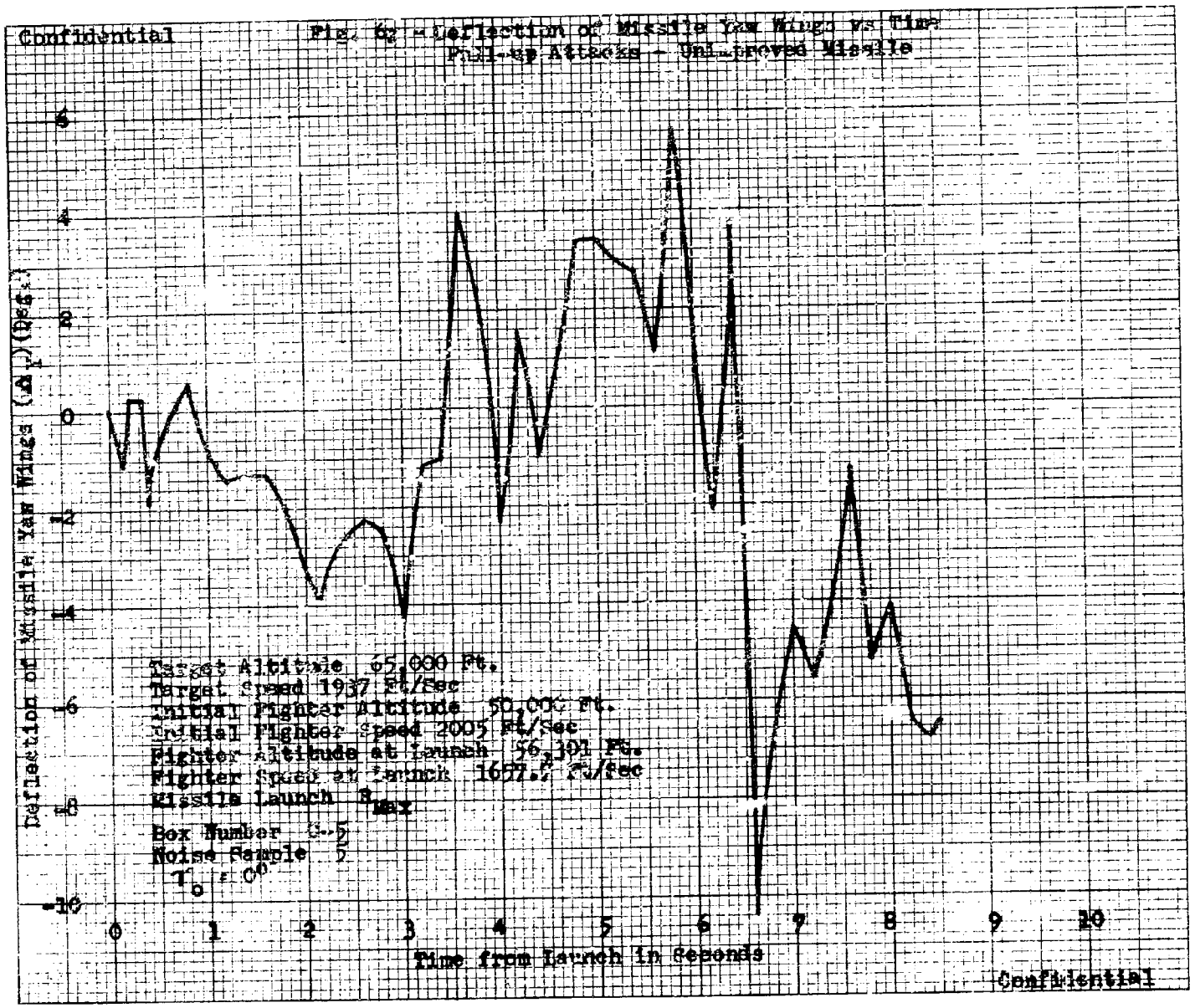
Fig. 62 - Deflection of Missile Yaw Wings vs Time
Pull-up Attacks - Unimproved Missile



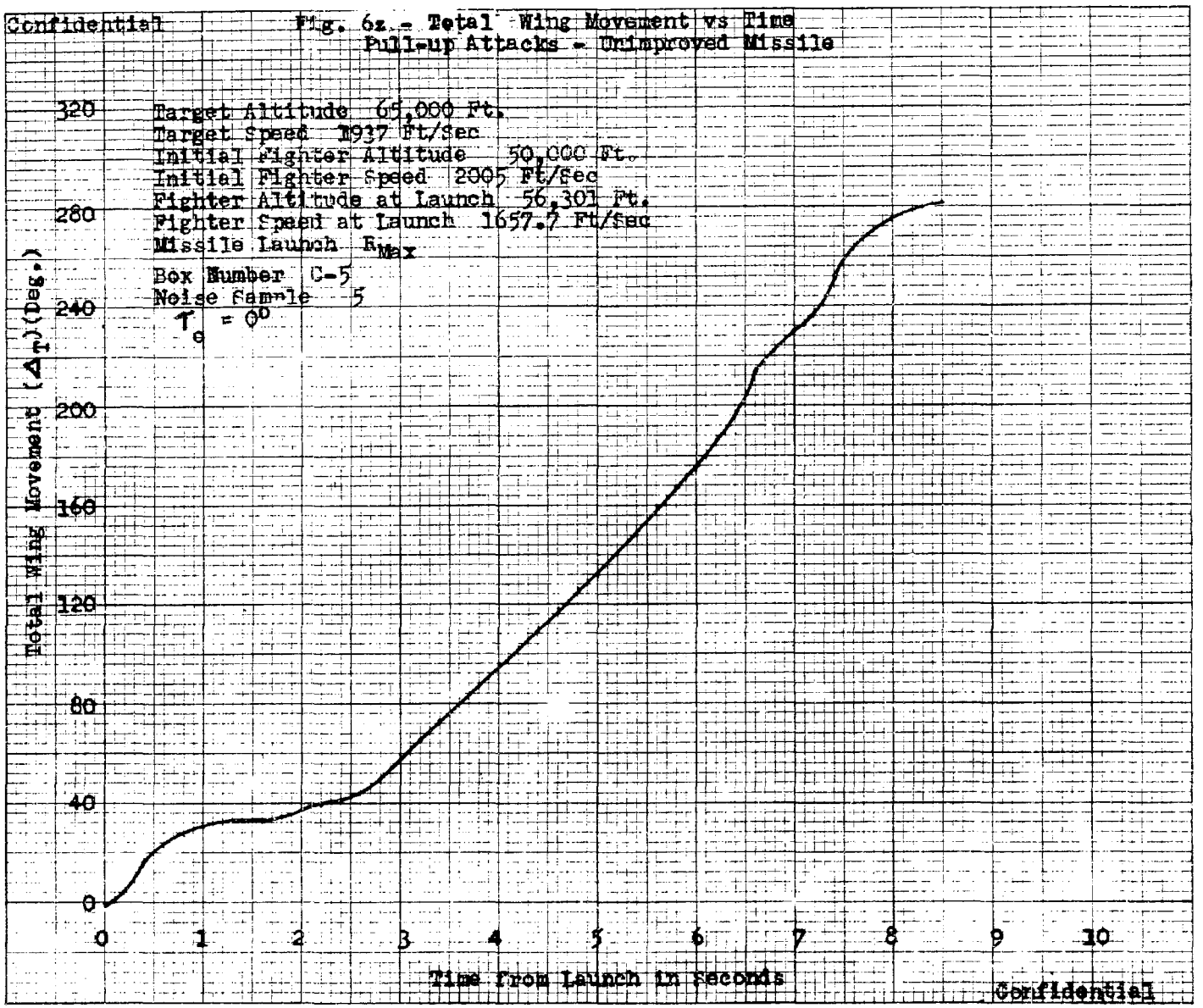


Fig. 6xx - Missile Altitude vs Time
Pull-up Attacks - Unimproved Missile

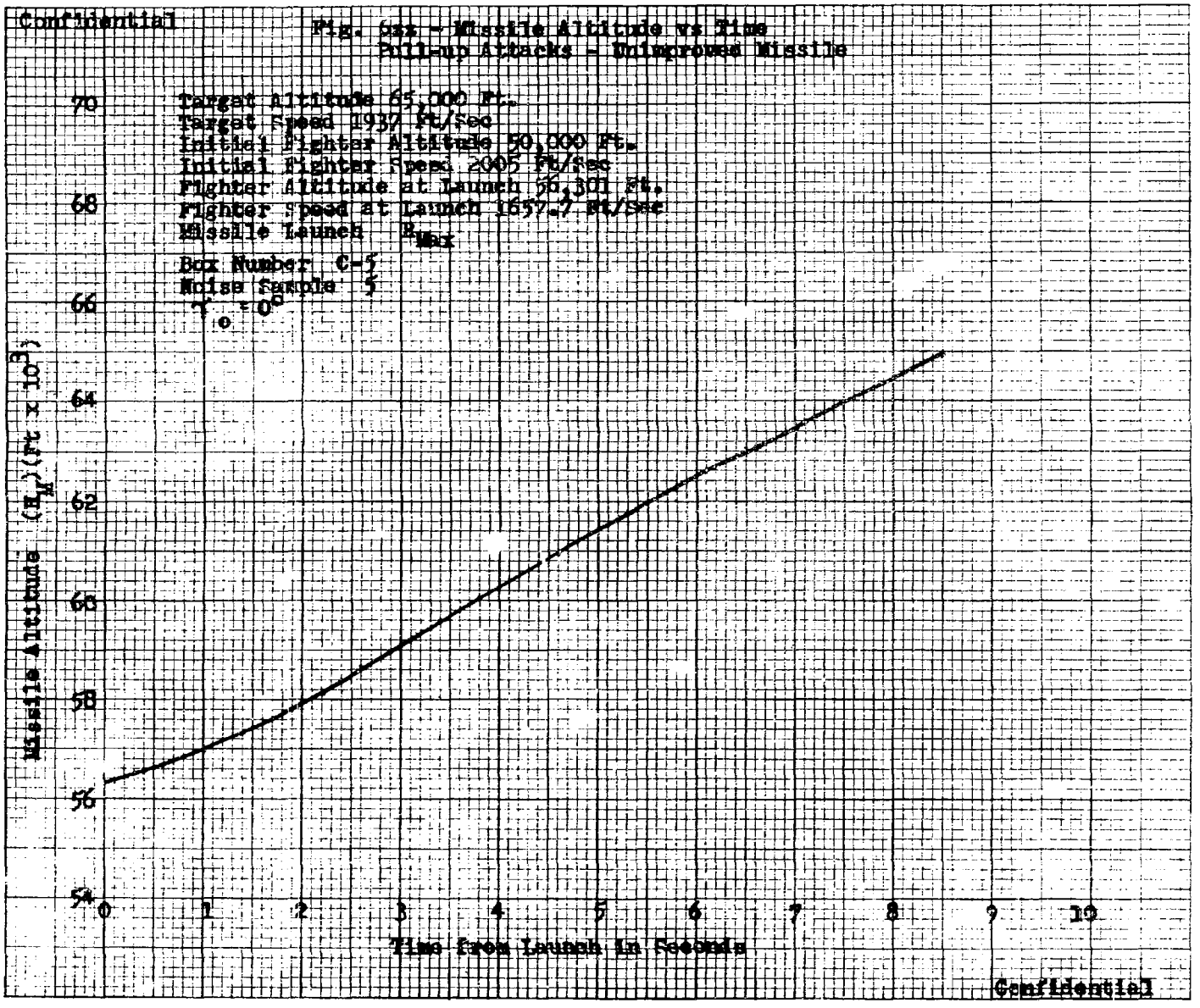


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Fig. 7a - Sparrow III Miss Distance - Pull-up Attacks
X-Y Miss Distance at the Target
$\gamma_\phi = 45°$, R_{max} Launch, Fighter Course - E-1
Unimproved Missile

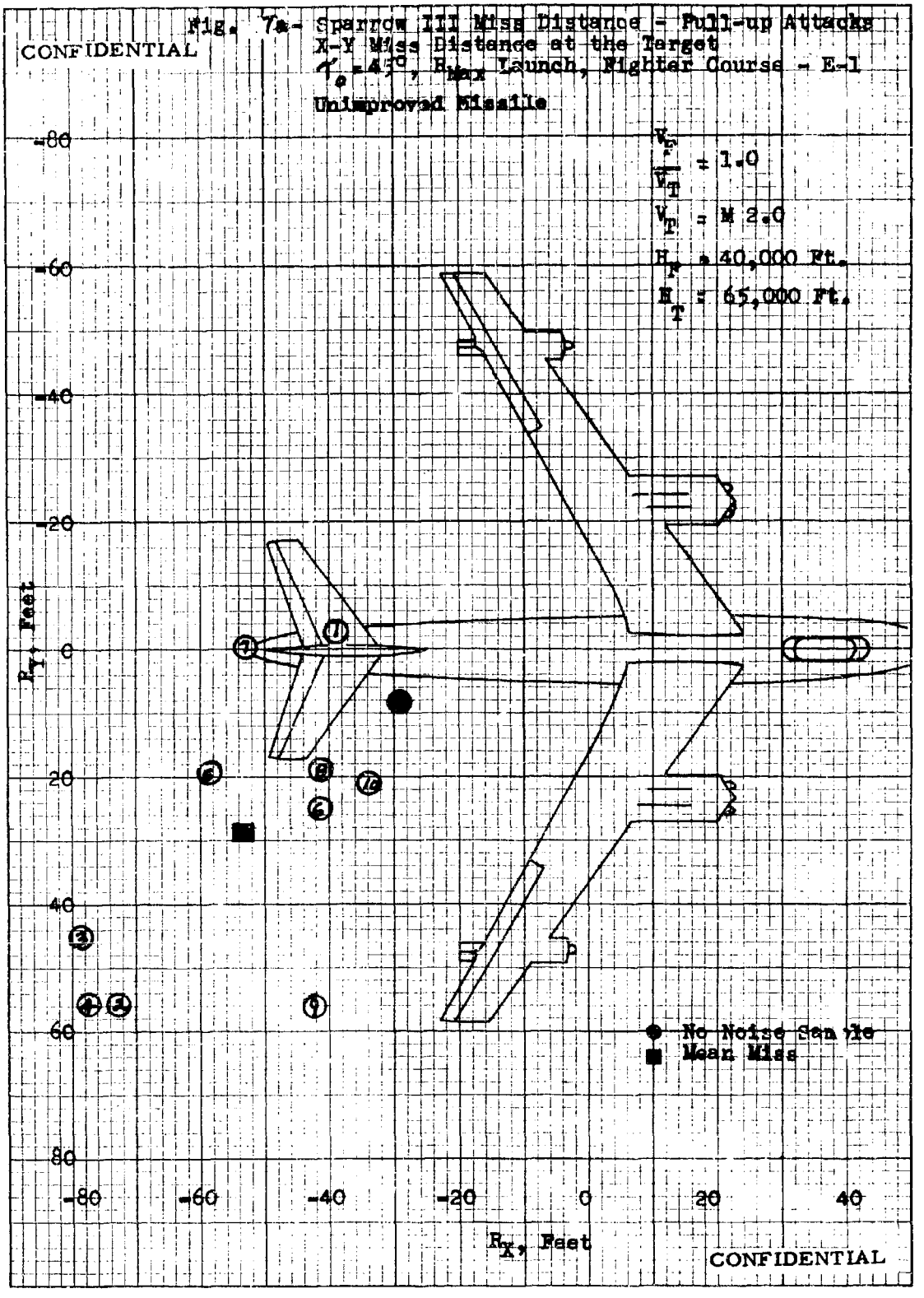

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Fig. 7b - Sparrow III Miss Distance - Pull-up Attacks
X-Z Miss Distance at the Target
$\tau_0 = 45^0$, R_{Max} Launch, Fighter Course - E-1
Unimproved Missile

V_F
$\frac{V_F}{V_T} = 1.0$
$V_T = M\ 2.0$
$H_F = 40,000$ Ft.
$H_T = 65,000$ Ft.

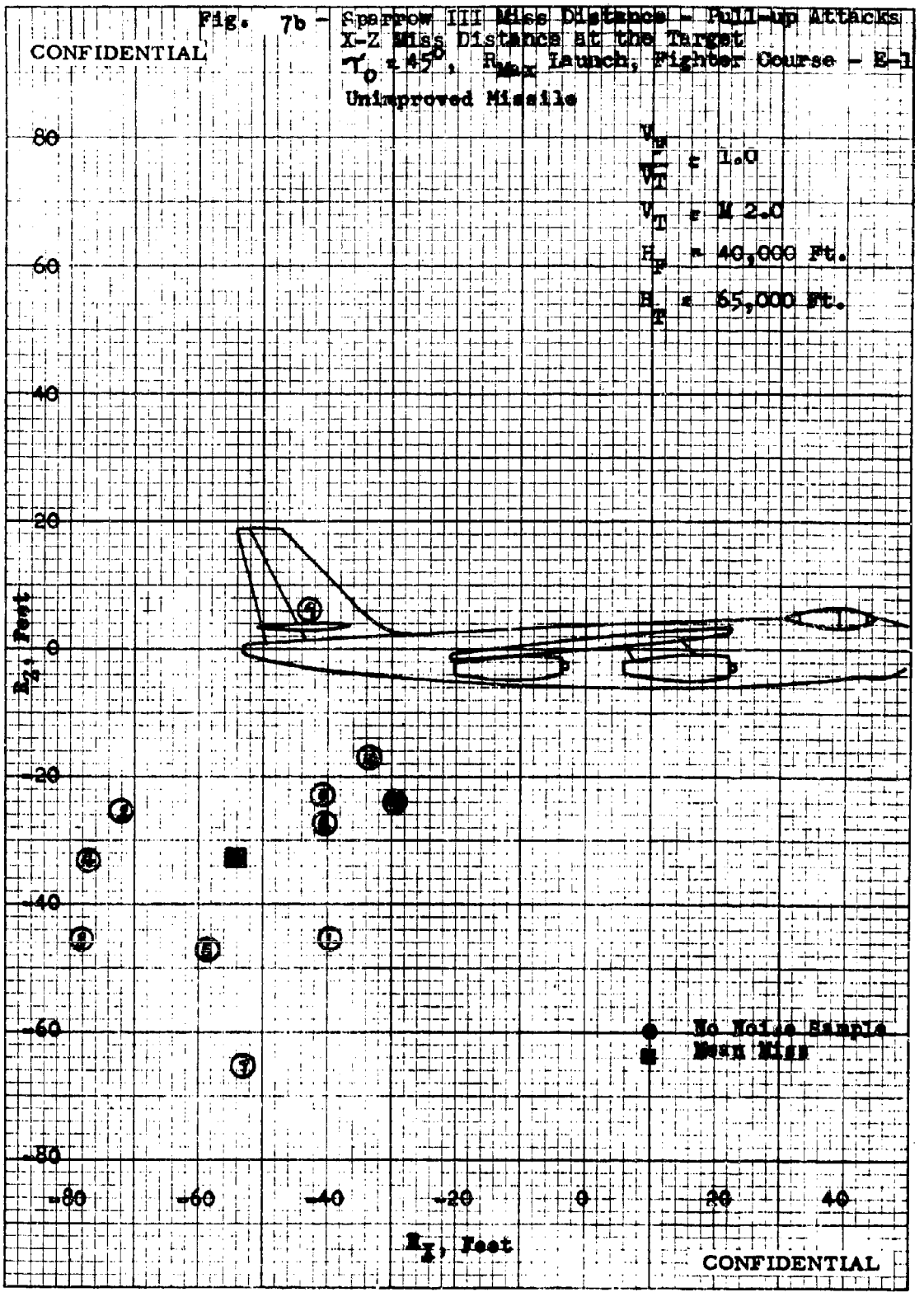

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Fig. 7c - Sparrow III Miss Distance - Pull-up Attacks
Y-Z Miss Distance at the Target
T_o = 45°, R_{Max} Launch, Fighter Course - E-I
Unimproved Missile

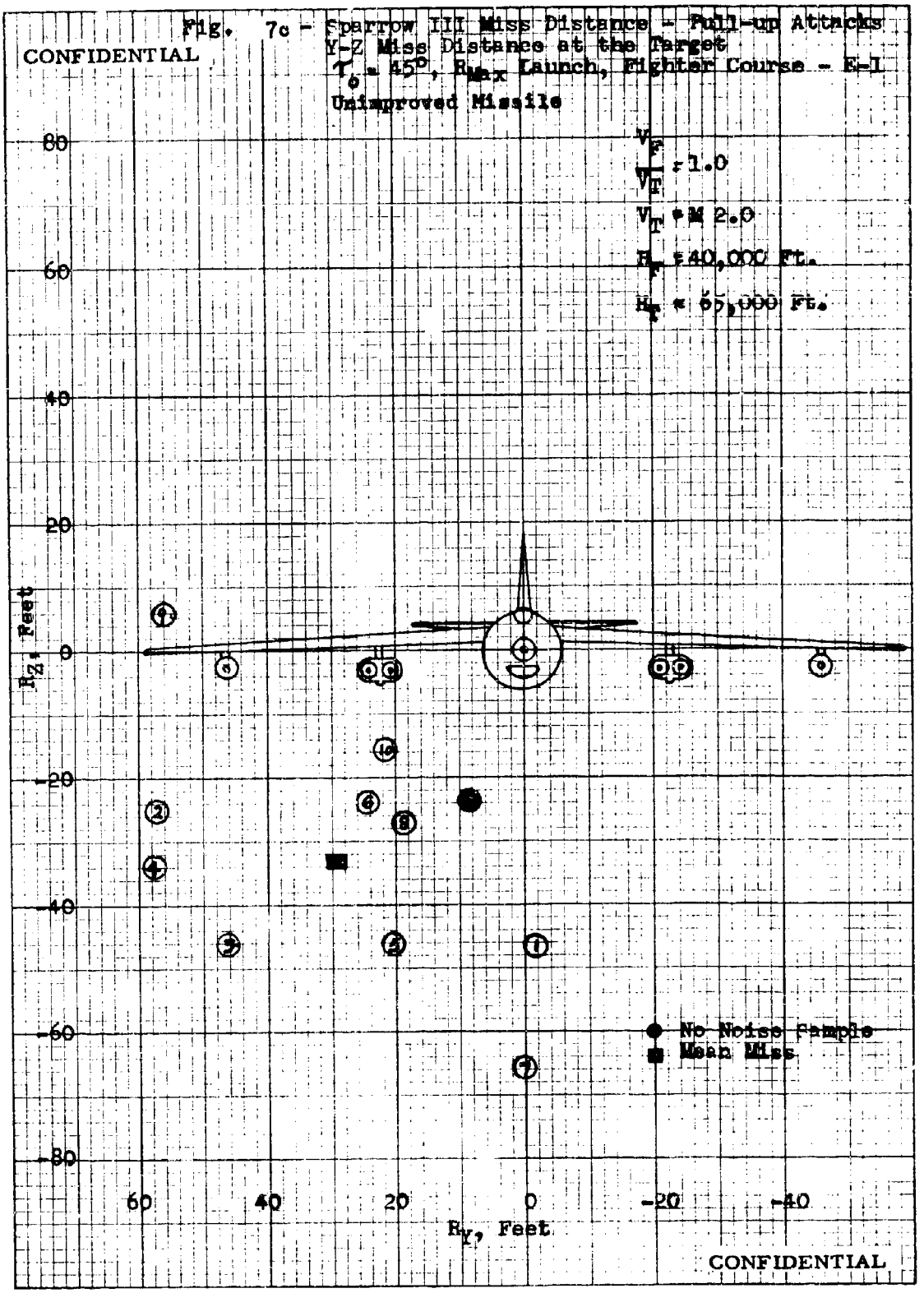

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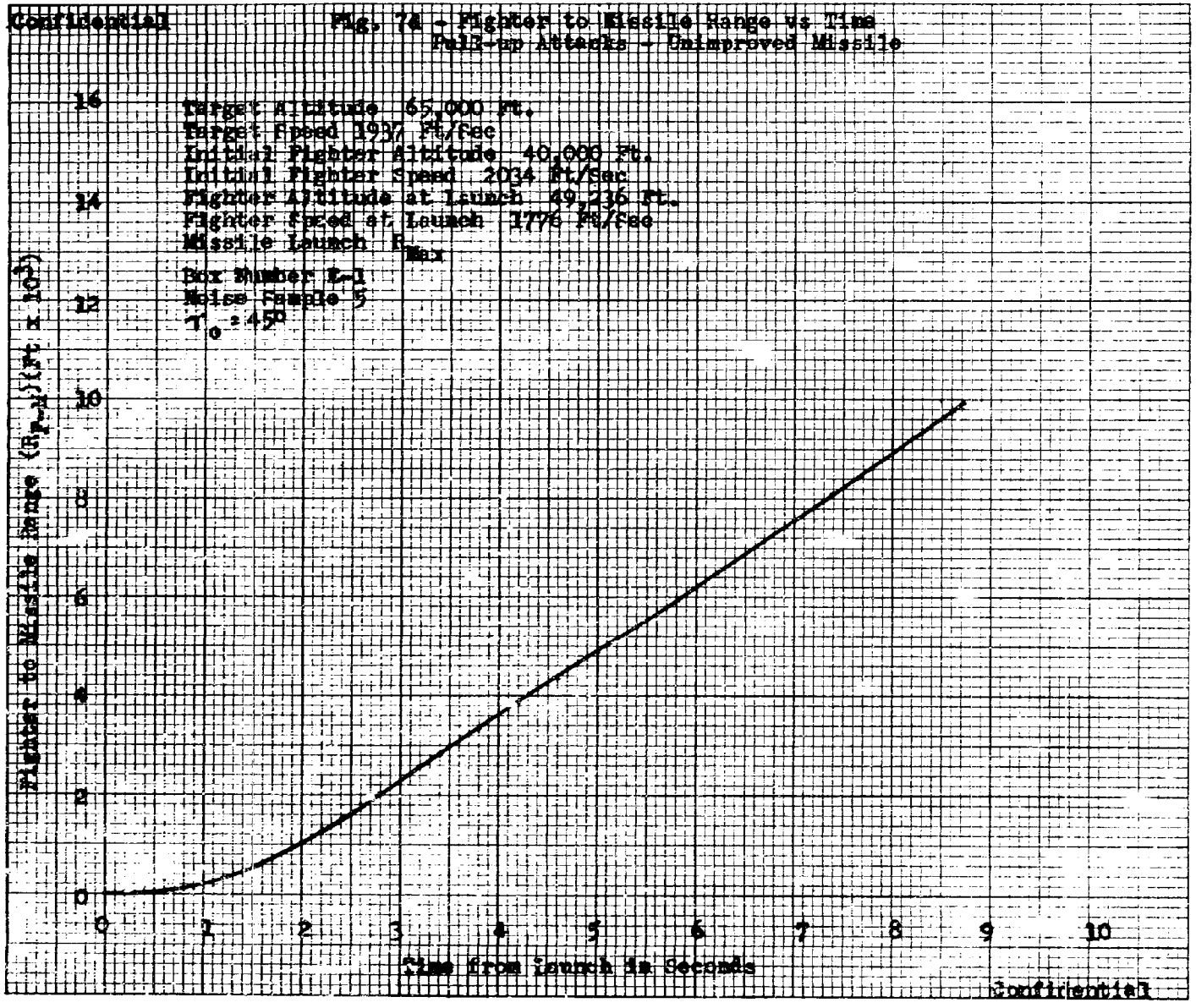
Fig. 74 - Fighter to Missile Range vs Time
Pull-up Attacks - Unimproved Missile



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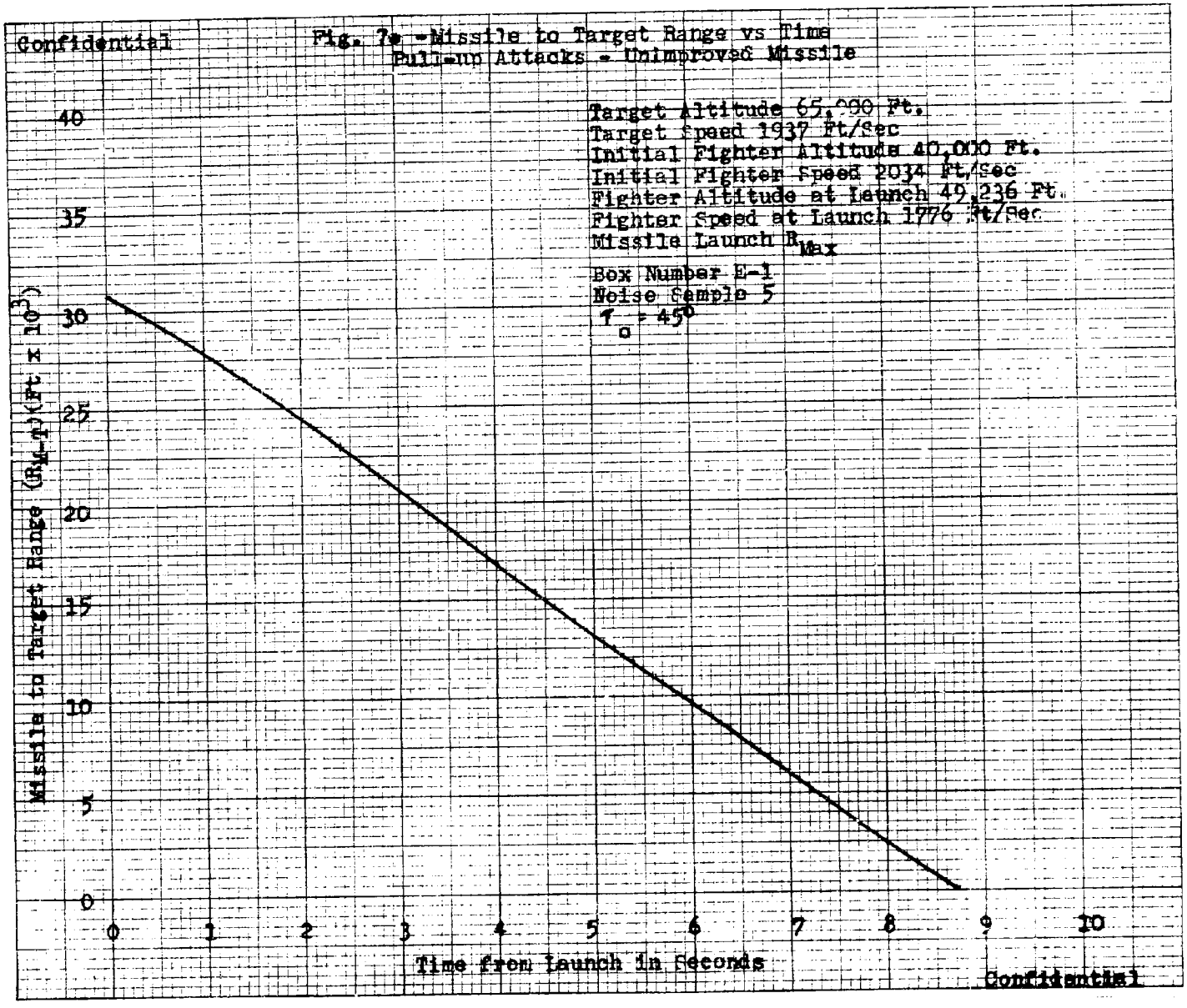
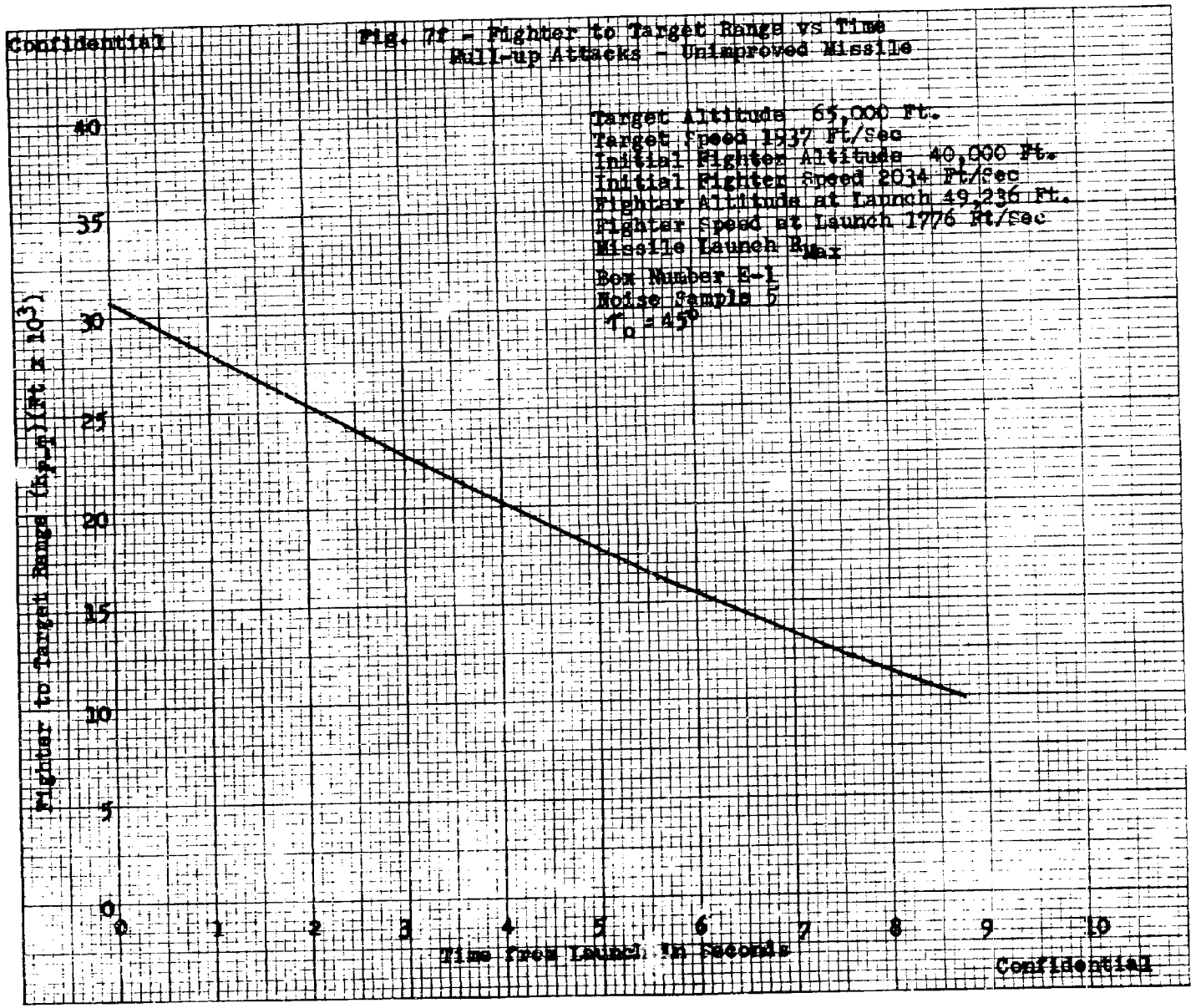
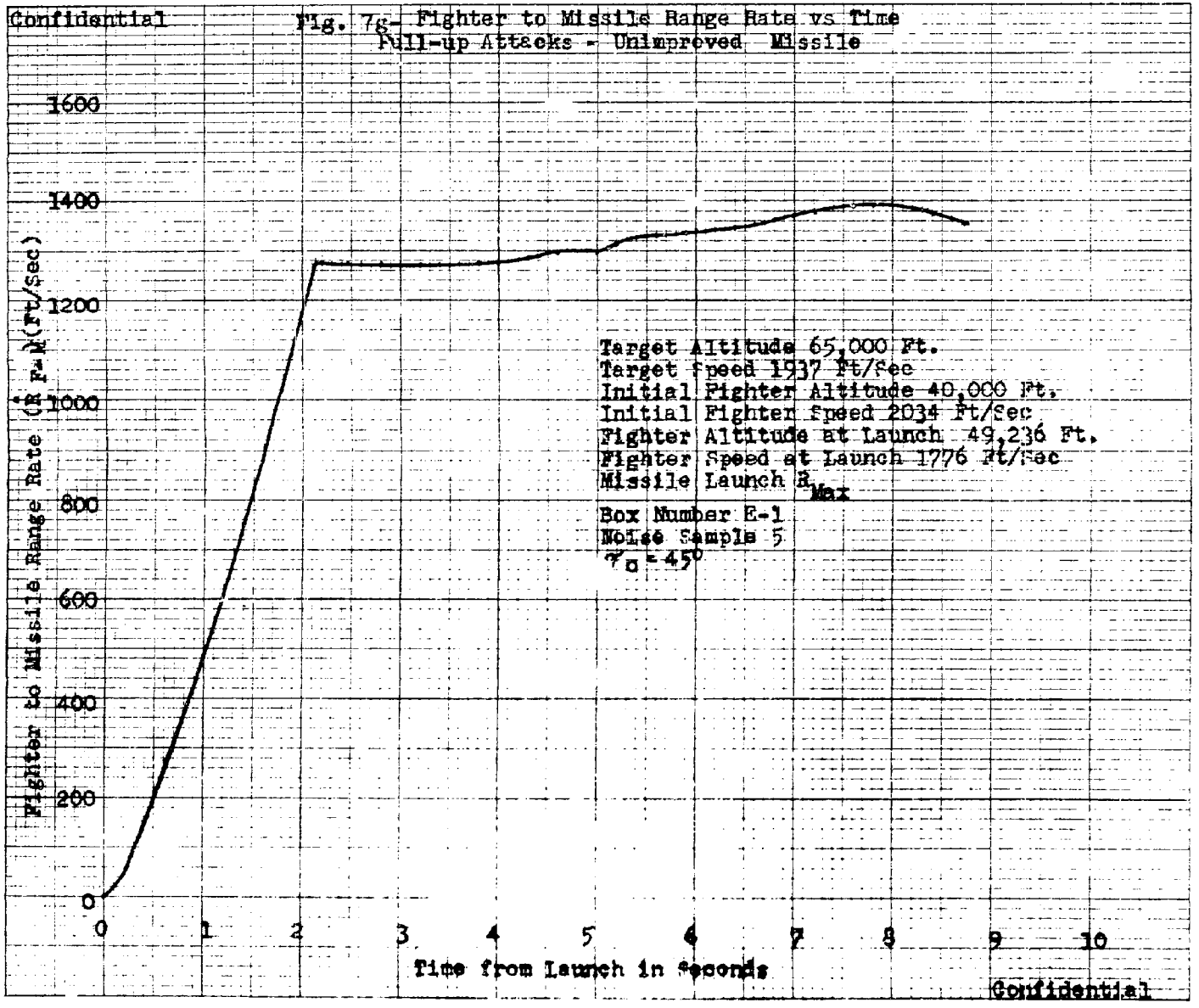


Fig. 71 - Fighter to Target Range vs Time
Hull-up Attacks - Unimproved Missile





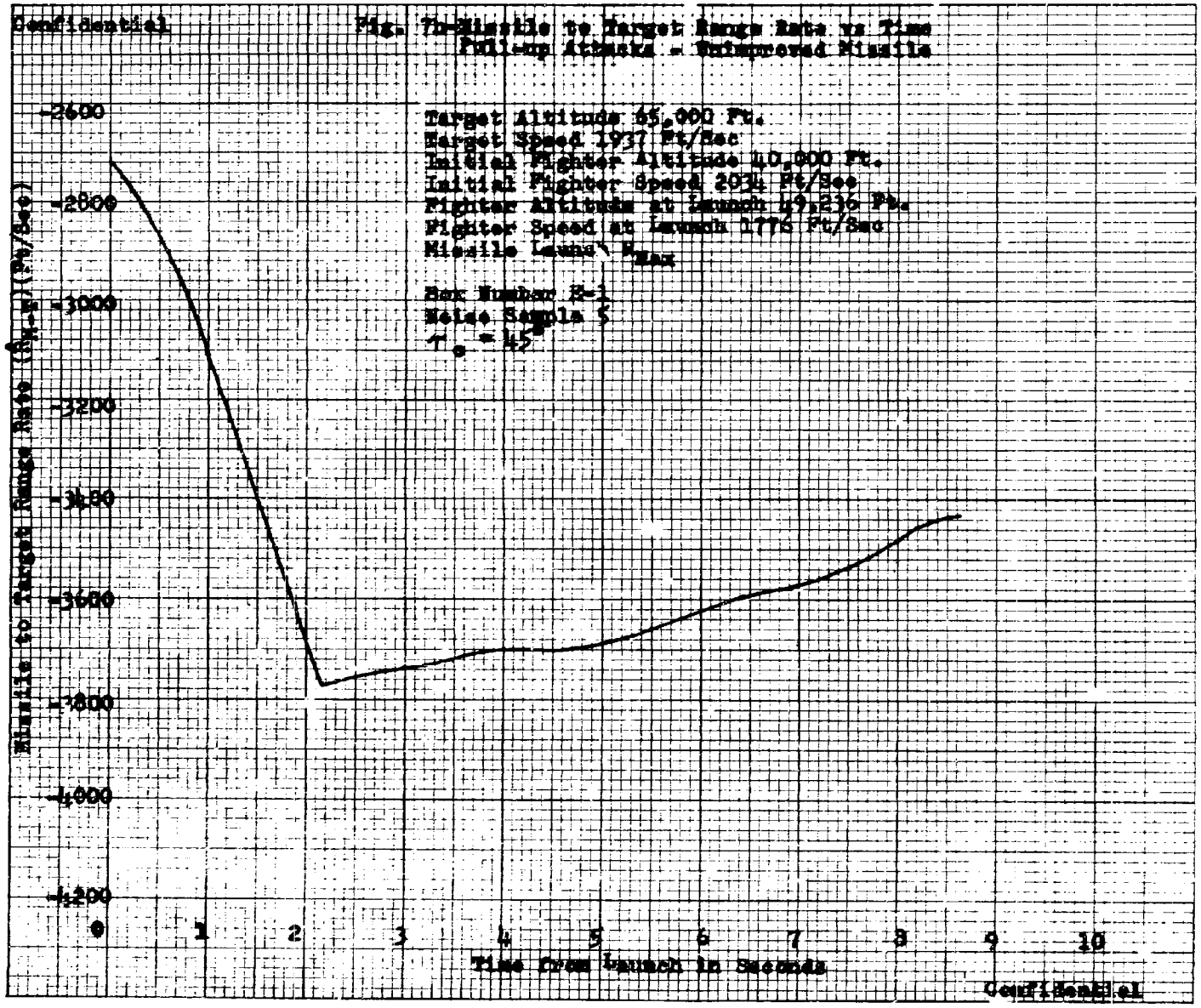

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Fig. Th-Missile to Target Range Rate vs Time
Pull-up Attacks - Unimproved Missile
Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 40,000 Ft.
Initial Fighter Speed 2034 Ft/Sec
Fighter Altitude at Launch 49,236 Ft.
Fighter Speed at Launch 1776 Ft/Sec
Missile Launch R_{max}
Box Number R-1
Mclee Sample 5
$\gamma_e = 45°$
Missile to Target Range Rate (Ft/Sec)
-2600
-2800
-3000
-3200
-3400
-3600
-3800
-4000
-4200
0
1
2
3
4
5
6
7
8
9
10
Time from launch in Seconds
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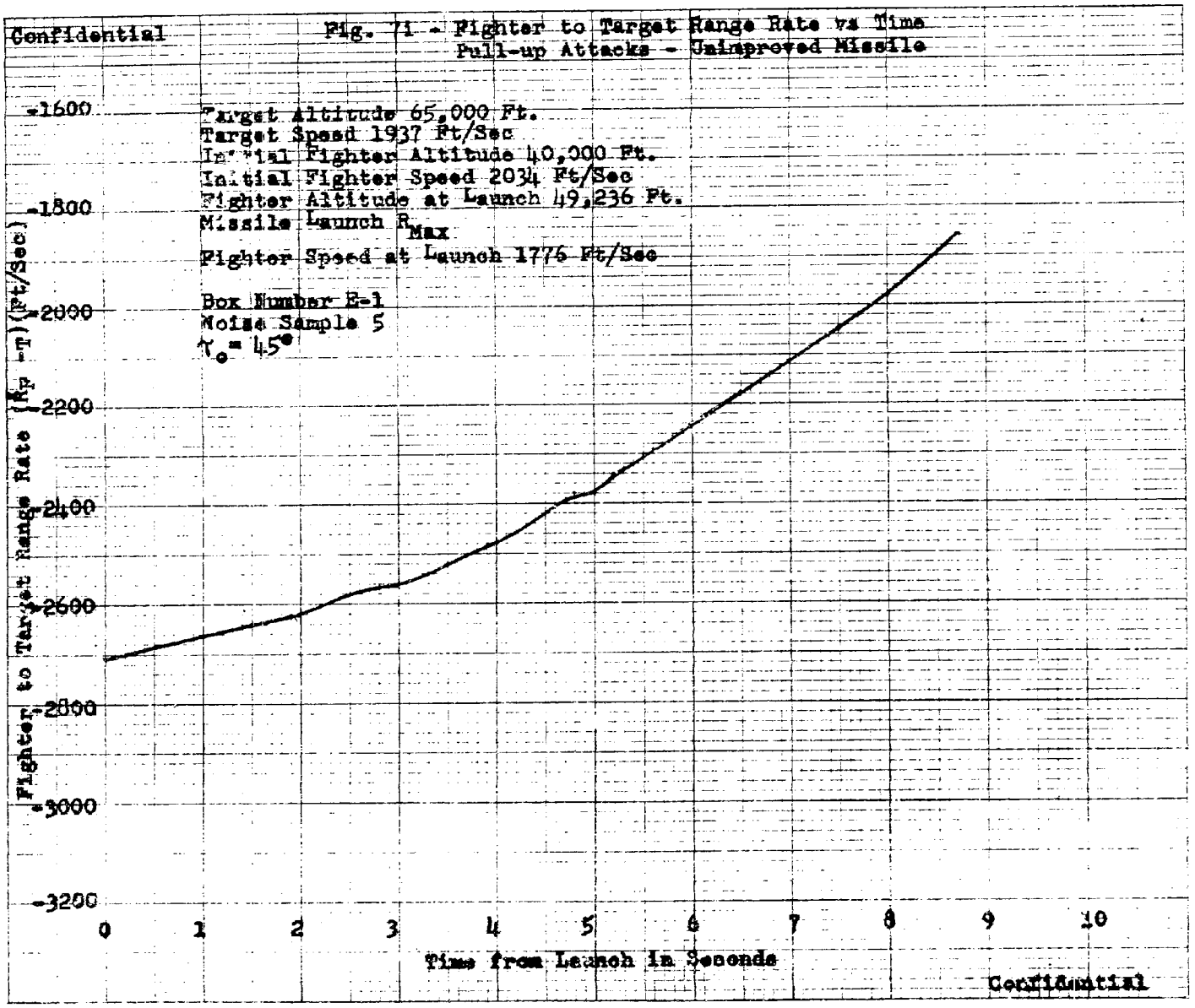

Fig. 7 - Antenna Azimuth Gimbal Angle of Missile vs Time
Pull-up Attacks - Unimproved Missile

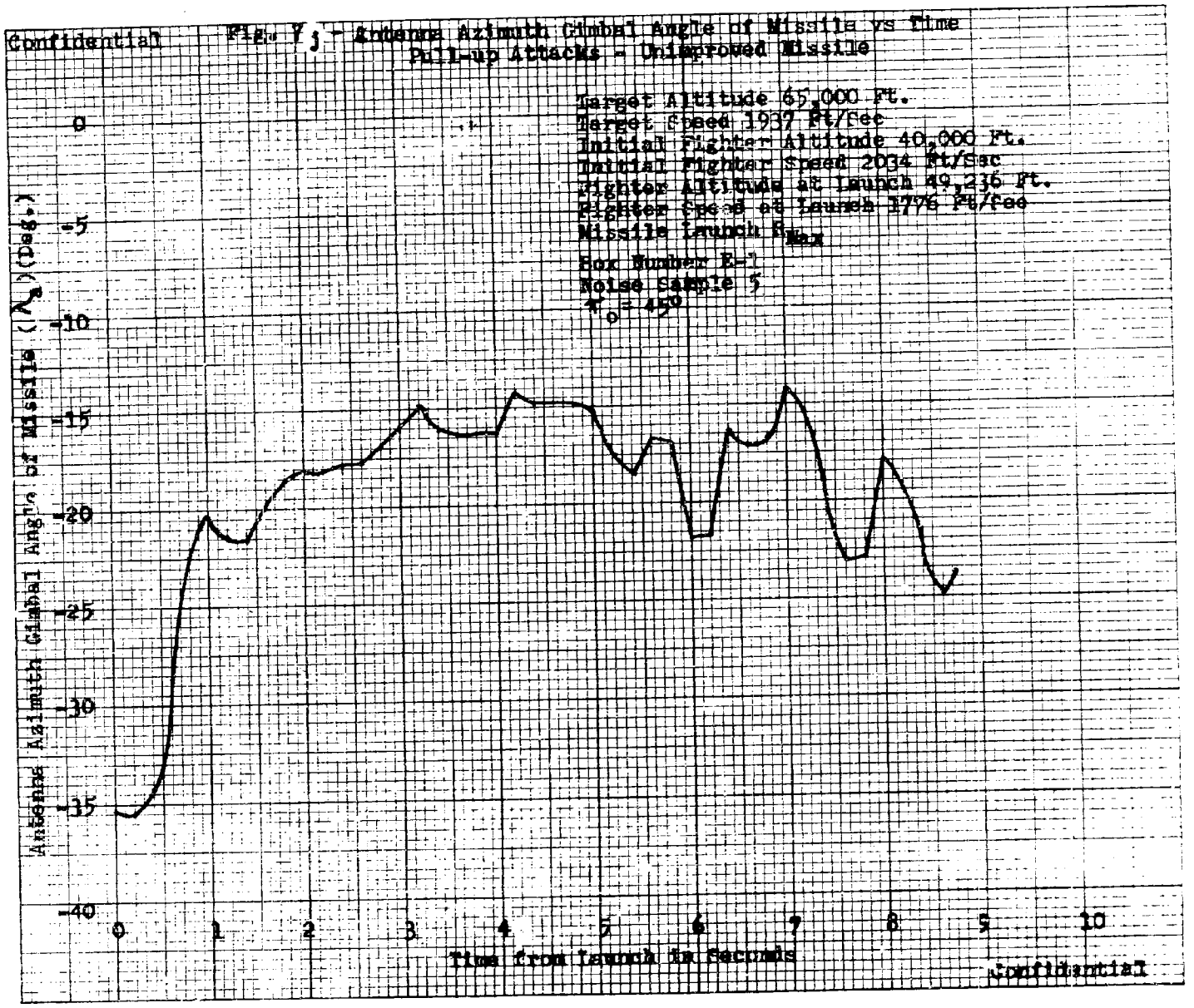

Fig. 7k - Antenna Elevation Gimbal Angle of Missile vs Time
Pull-up Attacks - Unimproved Missile

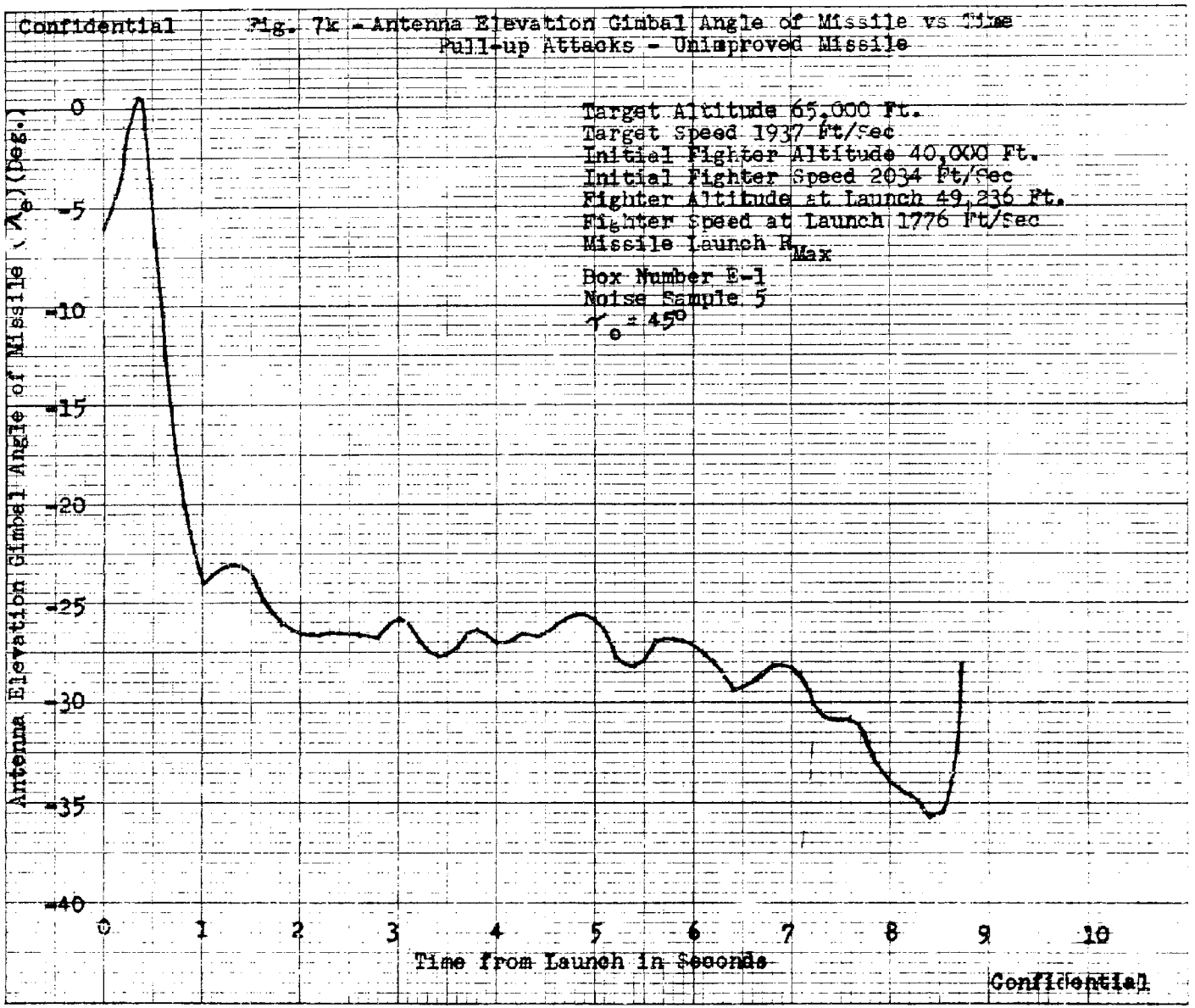

Fig. 71- Missile Lead Angle vs Time
Pull-up Attacks - Unimproved Missile

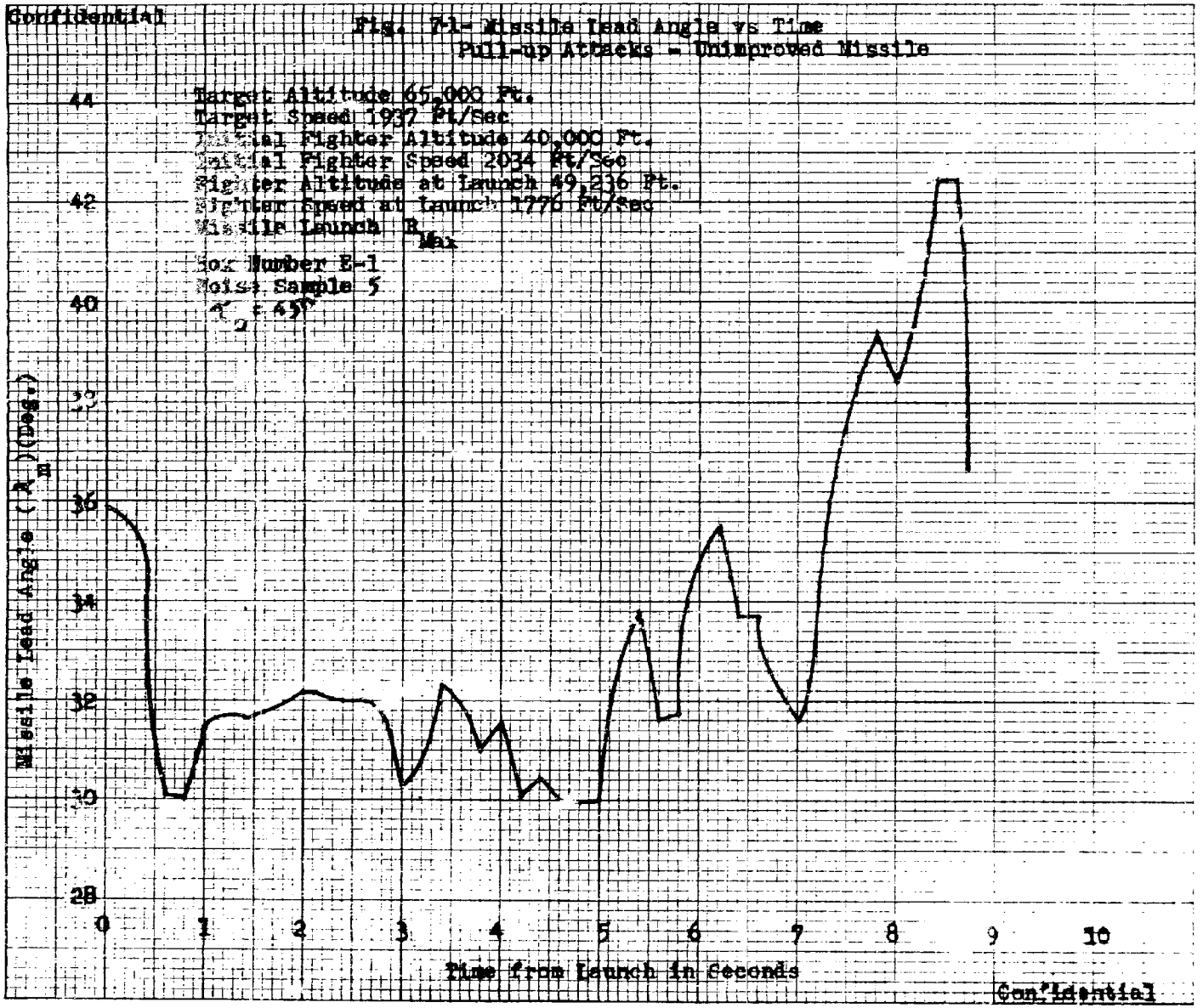

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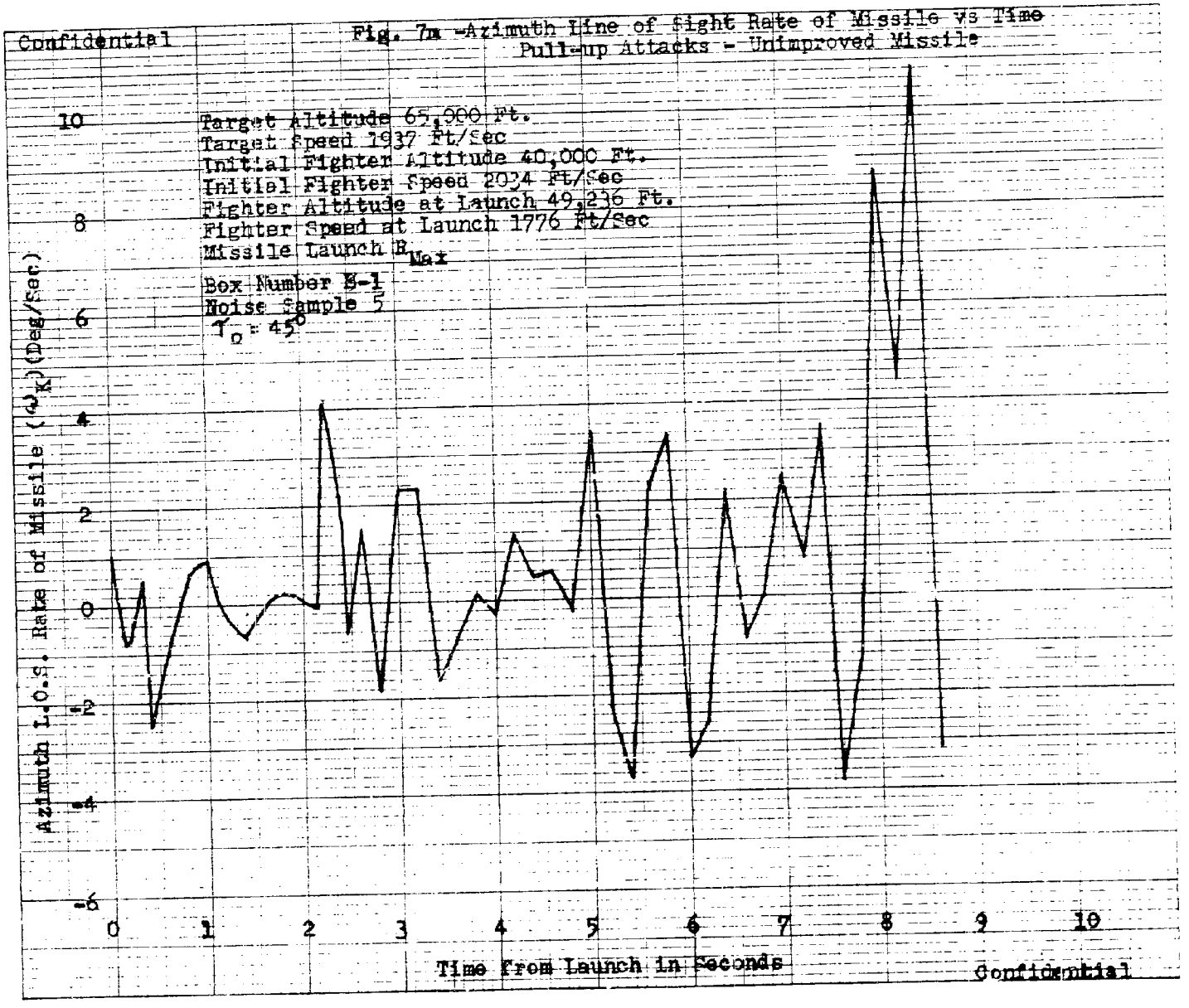
Fig. 7m -Azimuth Line of Sight Rate of Missile vs Time
Pull-up Attacks - Unimproved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 40,000 Ft.
Initial Fighter Speed 2034 Ft/Sec
Fighter Altitude at Launch 49,236 Ft.
Fighter Speed at Launch 1776 Ft/Sec
Missile Launch R_{Max}

Box Number B-1
Noise Sample 5
T_o = 45



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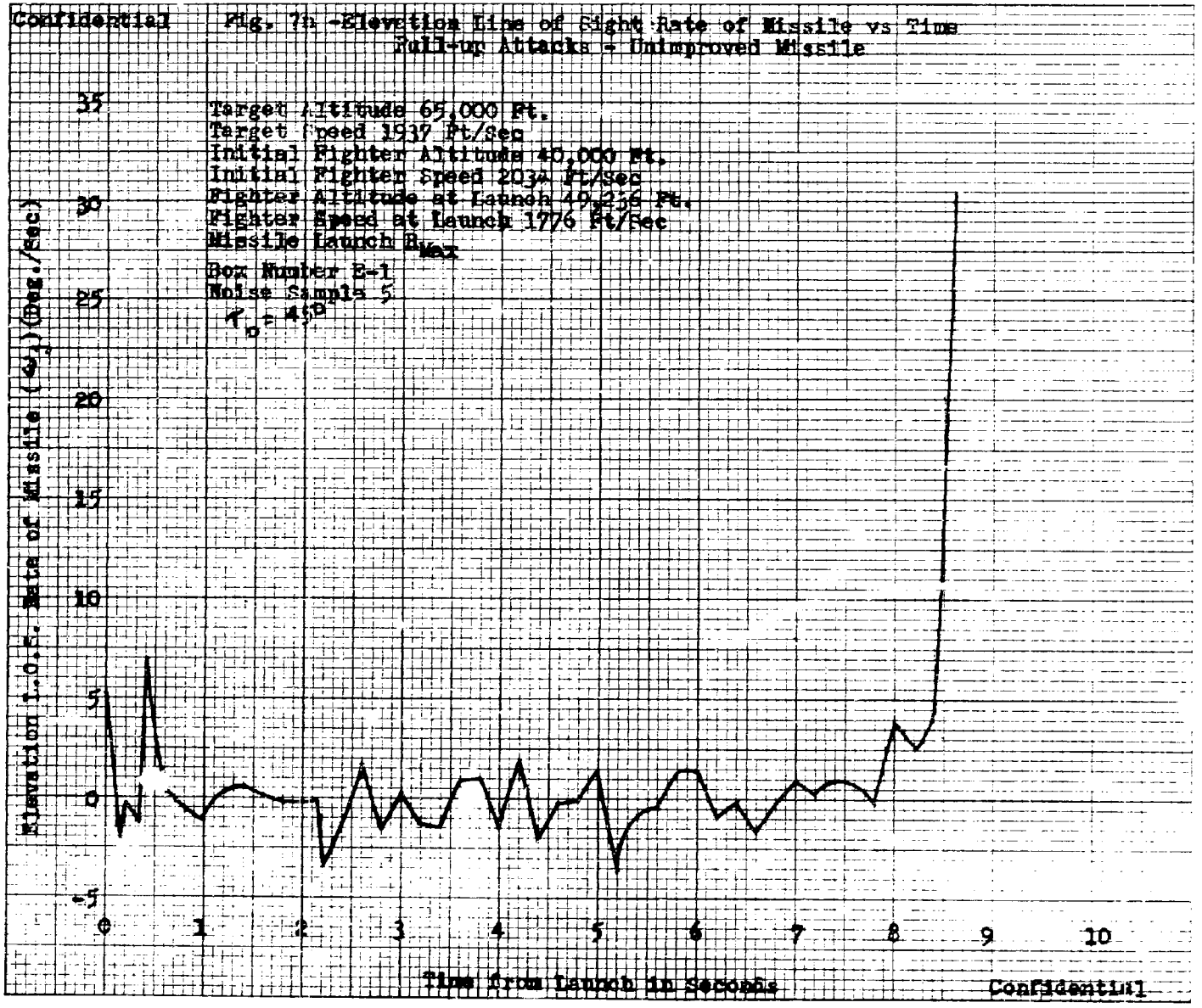
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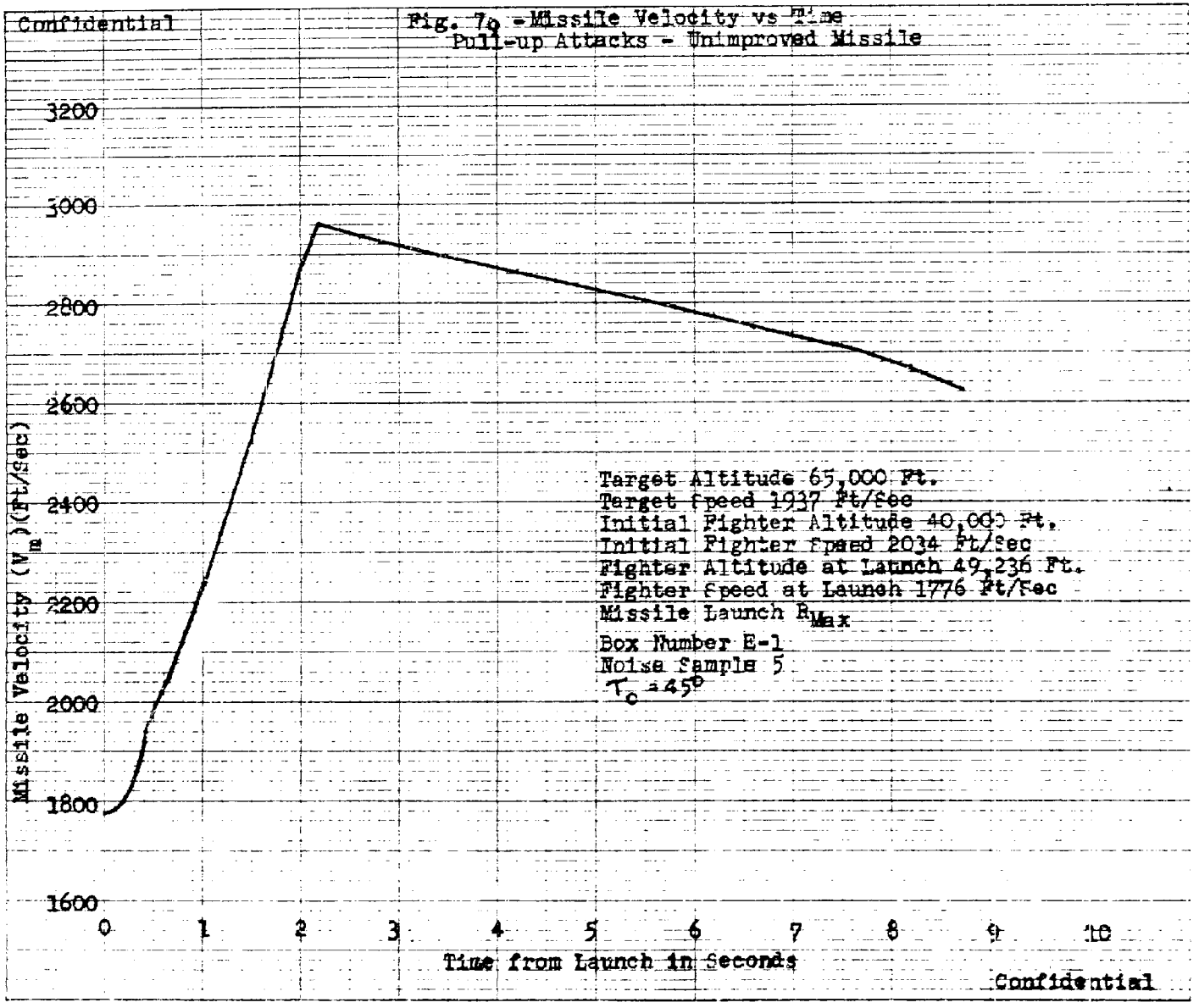
Fig. 7h -Elevation Line of Sight Rate of Missile vs Time
Pull-up Attacks - Unimproved Missile
Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 40,000 Ft.
Initial Fighter Speed 2034 Ft/Sec
Fighter Altitude at Launch 49,256 Ft.
Fighter Speed at Launch 1776 Ft/Sec
Missile Launch R Max
Box Number E-1
Noise Sample 5
$\gamma_D = 45^0$
Elevation L.O.S. Rate of Missile ($\dot{\epsilon}_y$)(deg./sec)
35
30
25
20
15
10
5
0
-5
0
1
2
3
4
5
6
7
8
9
10
Time from Launch in Seconds
Confidential

Fig. 7a - Missile Velocity vs Time
Pull-up Attacks - Unimproved Missile



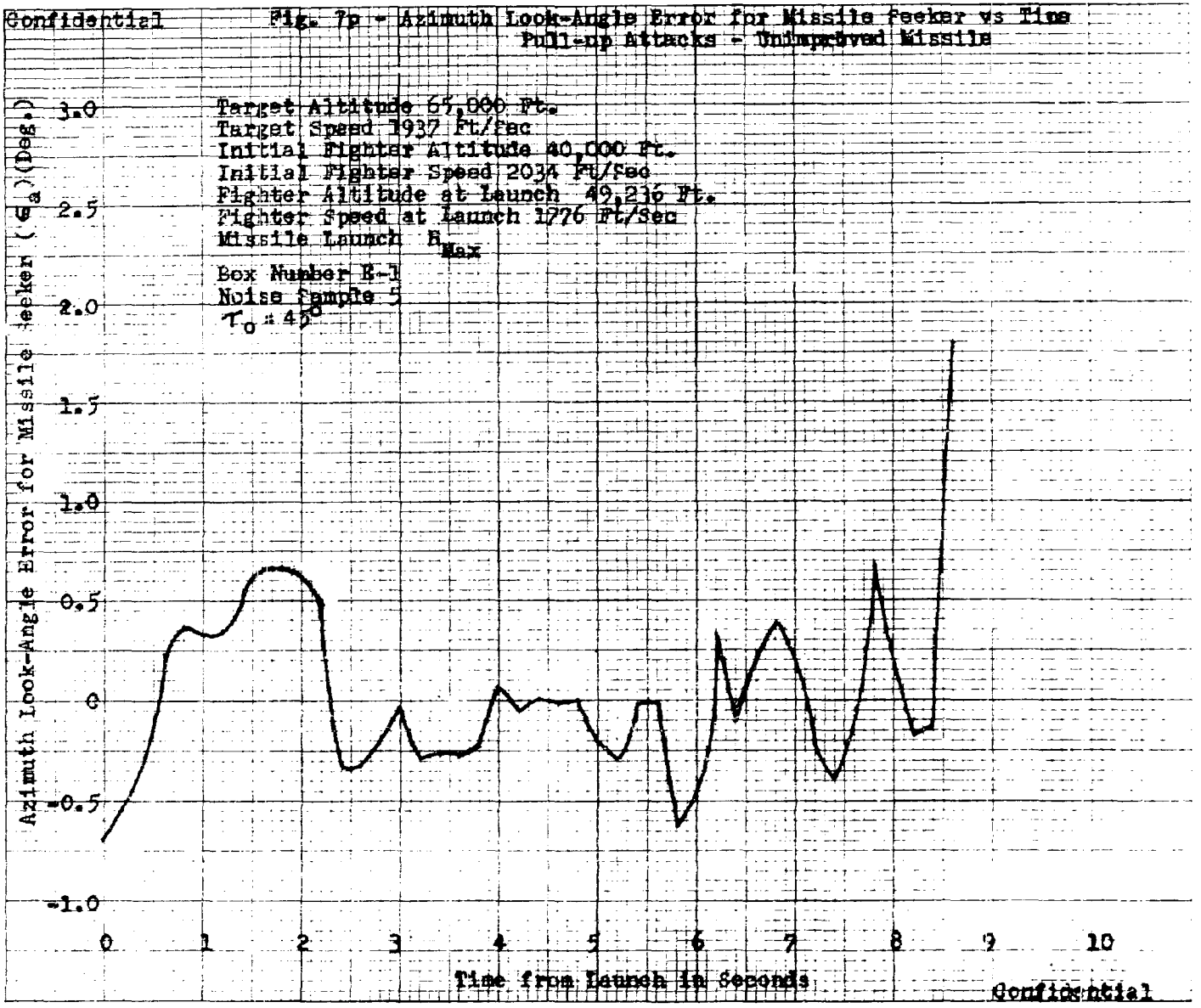

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Fig. 7p - Azimuth Look-Angle Error for Missile Seeker vs Time
Pull-up Attacks - Unimproved Missile
Target Altitude 65,000 Ft.
Target Speed 1937 Ft/sec
Initial Fighter Altitude 40,000 Ft.
Initial Fighter Speed 2034 Ft/Sec
Fighter Altitude at Launch 49,210 Ft.
Fighter Speed at Launch 1776 Ft/Sec
Missile Launch R_{Max}
Box Number E-1
Noise Sample 5
$\tau_o = 4^o$
Azimuth Look-Angle Error for Missile Seeker (ε_a)(Deg.)
3.0
2.5
2.0
1.5
1.0
0.5
0
-0.5
-1.0
0
1
2
3
4
5
6
7
8
9
10
Time from Launch in Seconds
Confidential

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Fig. 7q - Elevation Look-Angle Error for Missile Seeker vs Time
Pull-up Attacks - Unimproved Missile

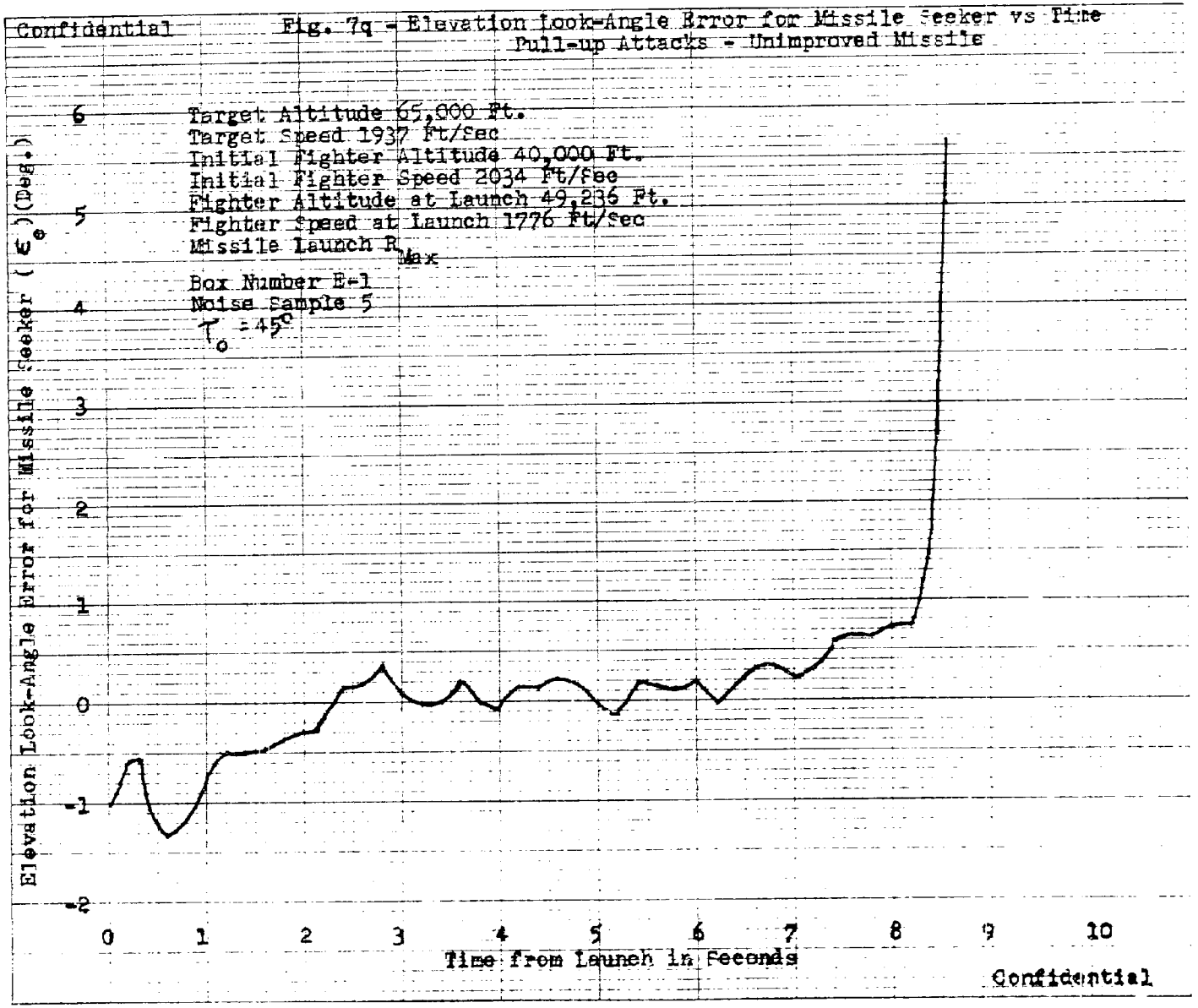

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Fig. 7r -Missile Angle of Attack vs Time
Pull-α_q Attacks - Unimproved Missile

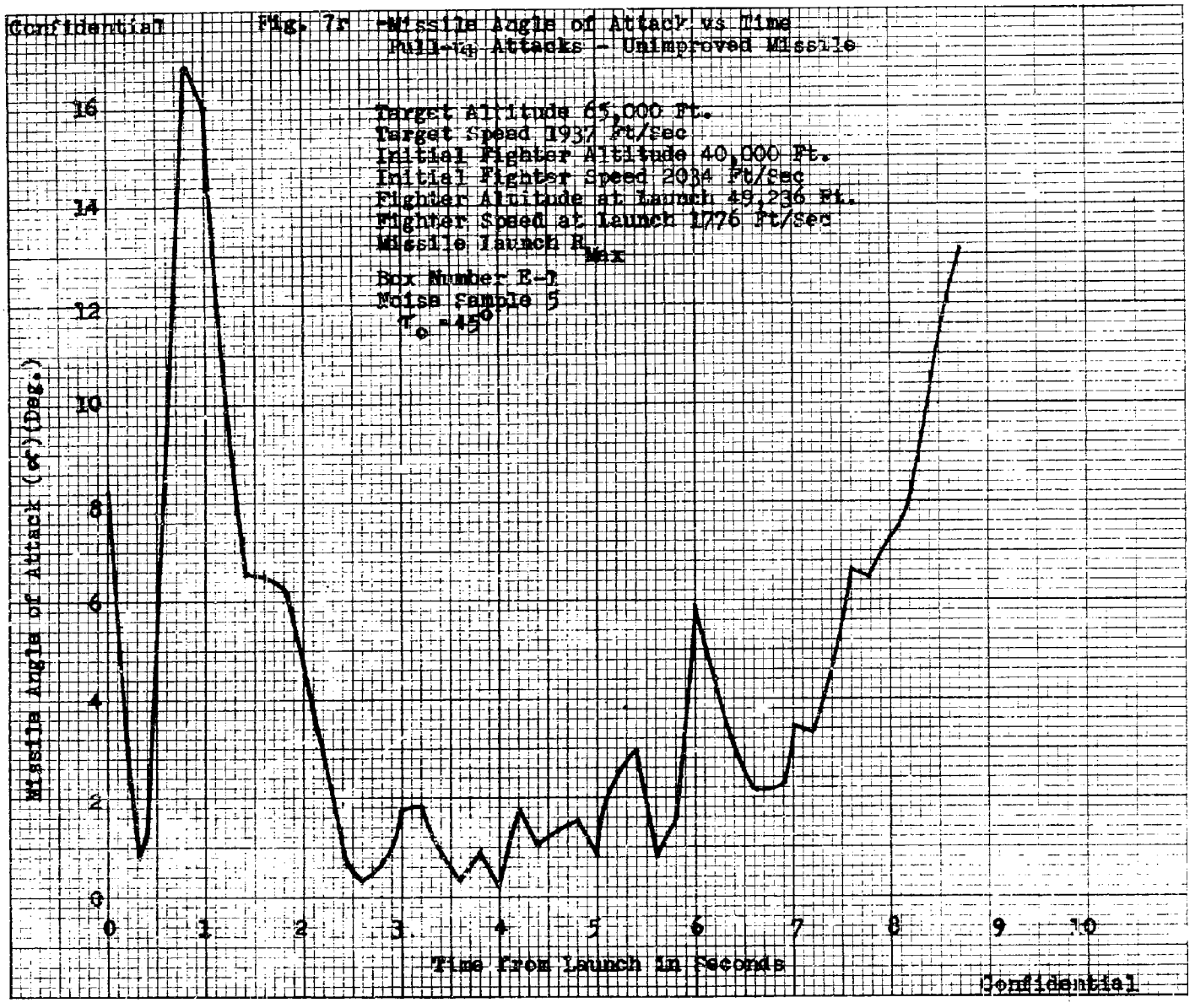

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Fig. 7a Missile and Fighter Roll Angle vs Time
Pull-up Attacks-Unimproved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 40,000 Ft.
Initial Fighter Speed 2034 Ft/Sec
Fighter Altitude at Launch 49,236 Ft.
Fighter Speed at Launch 1776 Ft/Sec
Missile Launch - R_{Max}

Box Number E-1
Noise Sample 5
$\gamma_o = 45^\circ$

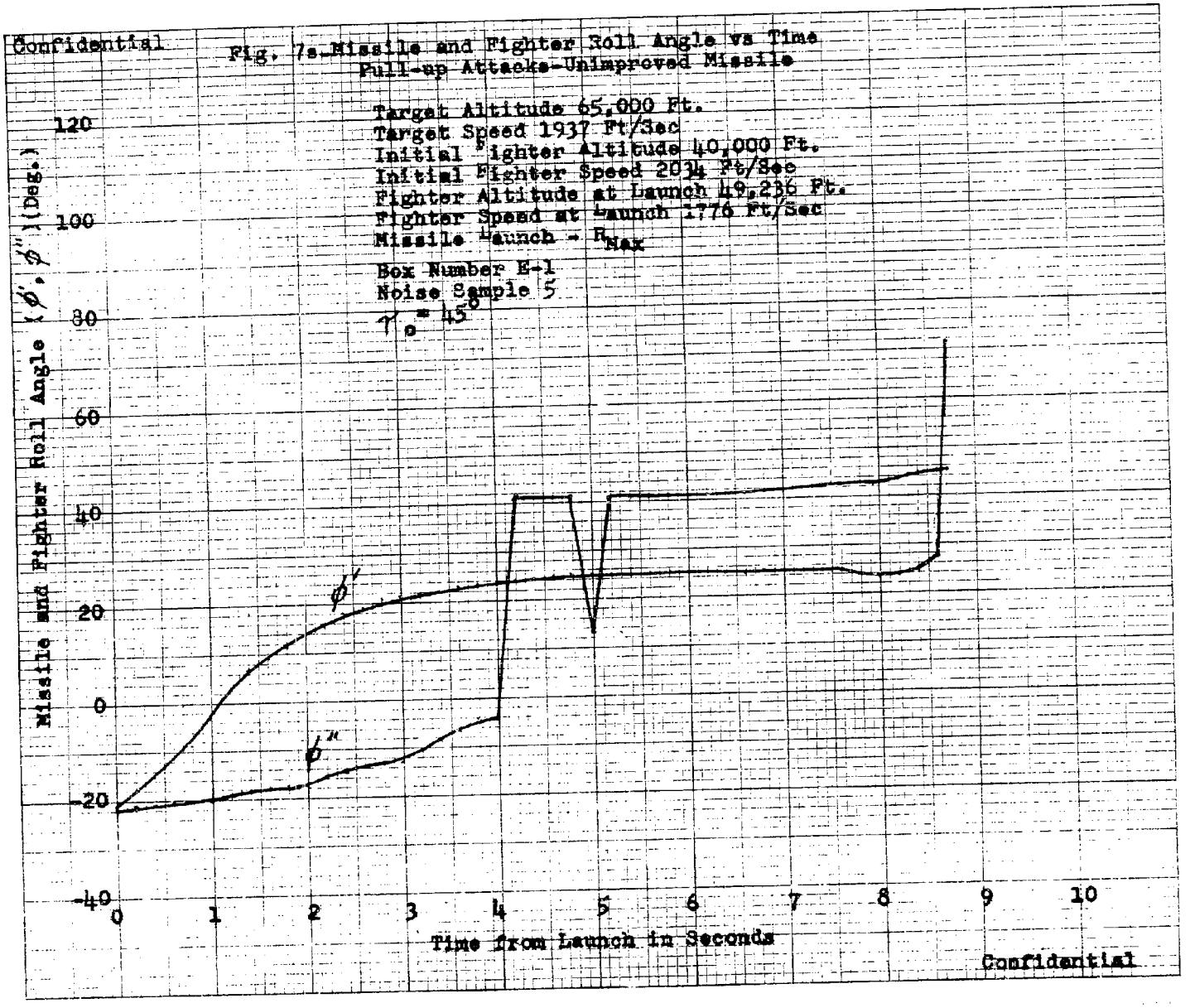

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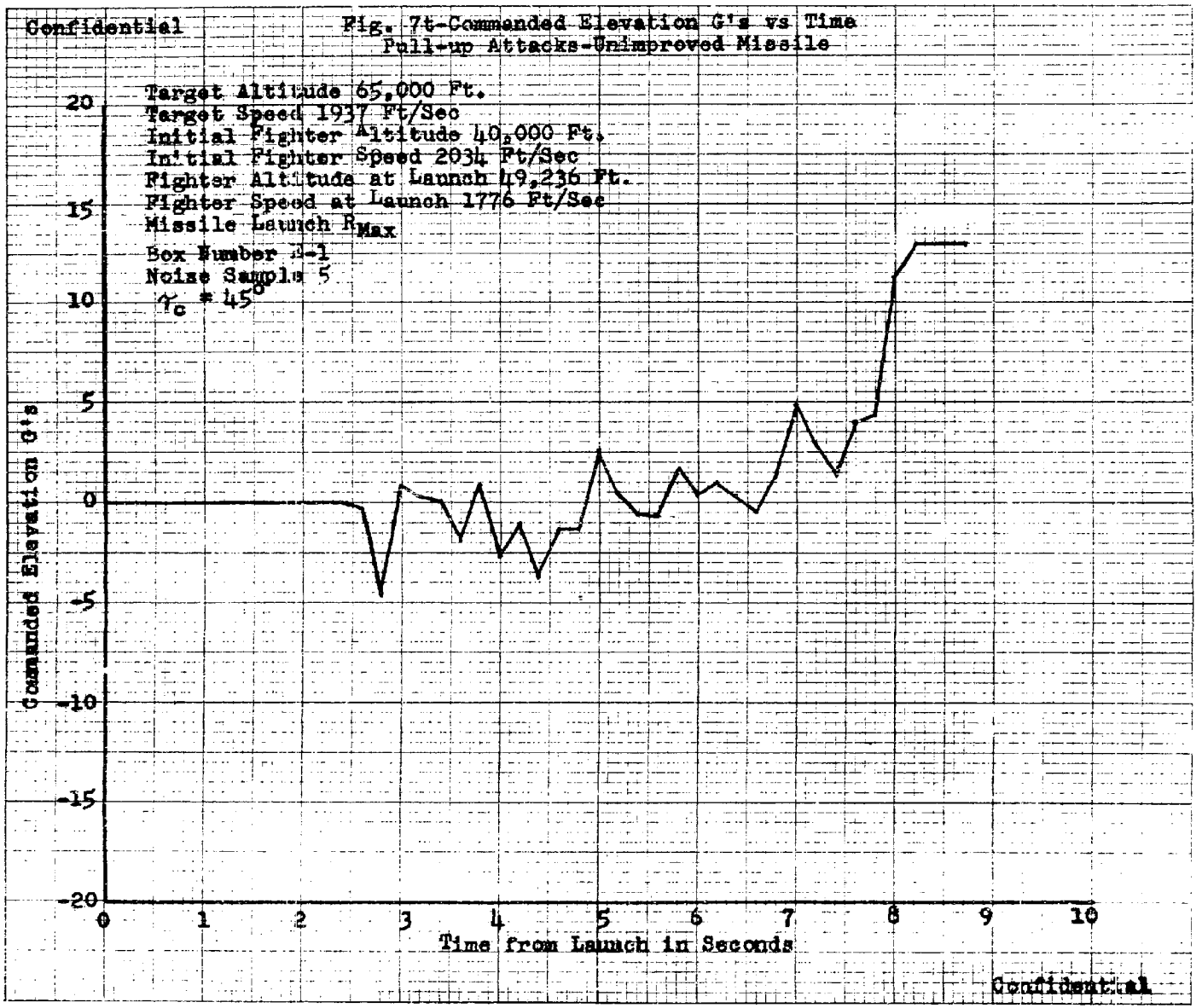
Fig. 7t-Commanded Elevation G's vs Time
Pull-up Attacks-Unimproved Missile



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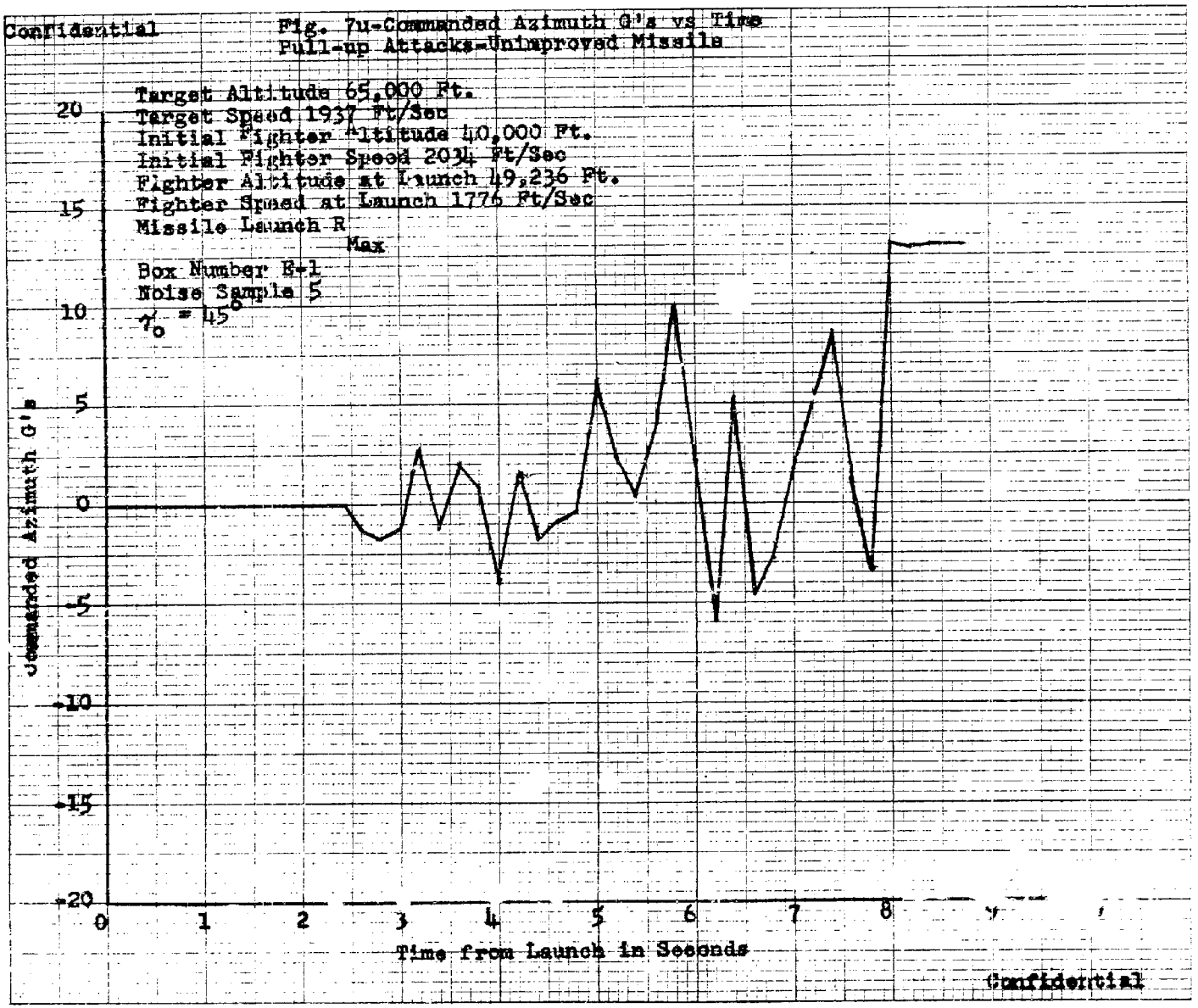

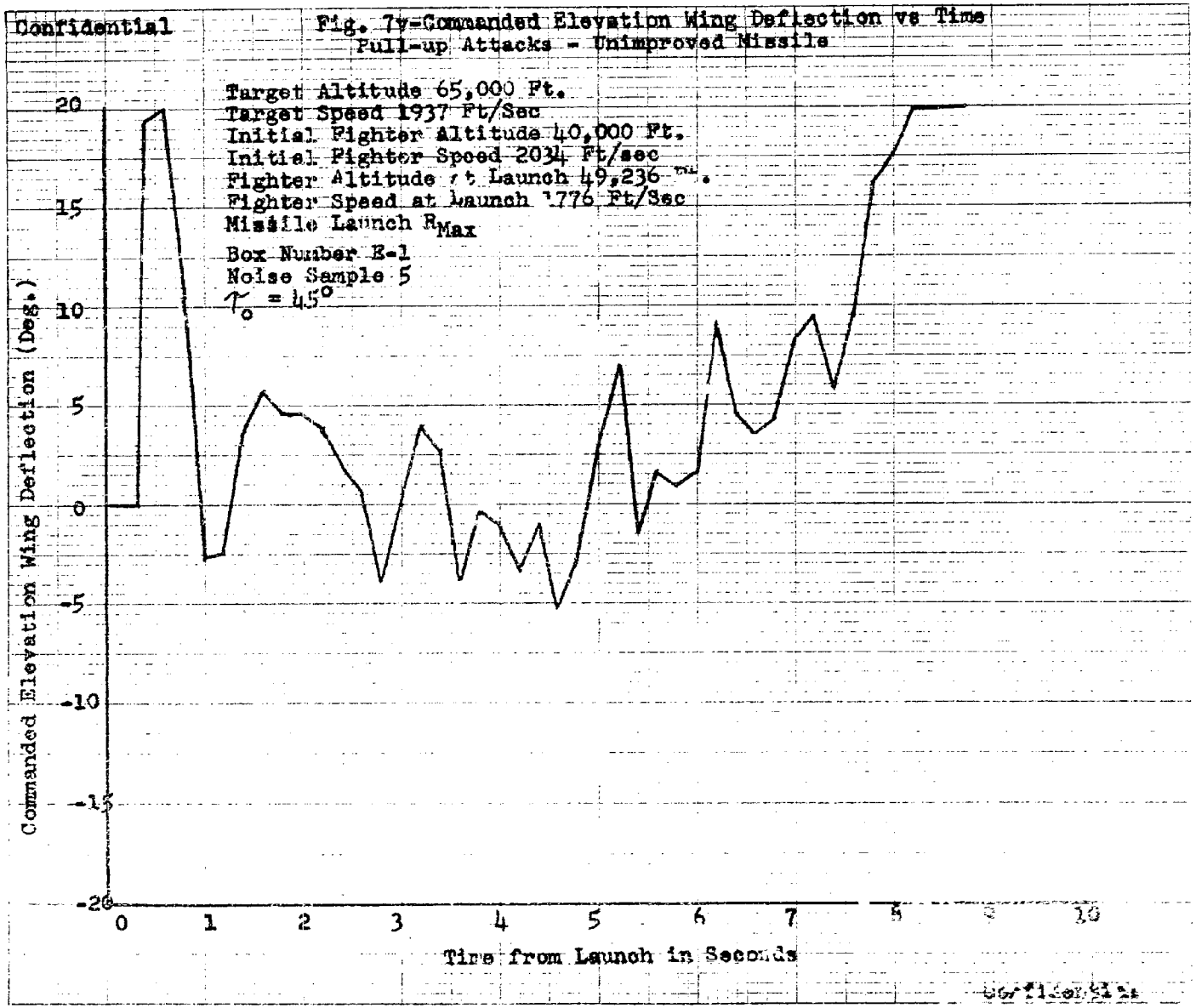
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Fig. 7y-Commanded Elevation Wing Deflection vs Time
Pull-up Attacks - Unimproved Missile
Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 40,000 Ft.
Initial Fighter Speed 2034 Ft/sec
Fighter Altitude at Launch 49,236 Ft.
Fighter Speed at Launch 1776 Ft/Sec
Missile Launch R_{Max}
Box Number E-1
Noise Sample 5
$\gamma_o = 45°$
Commanded Elevation Wing Deflection (Deg.)
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
10
Time from Launch in Seconds
Confidential

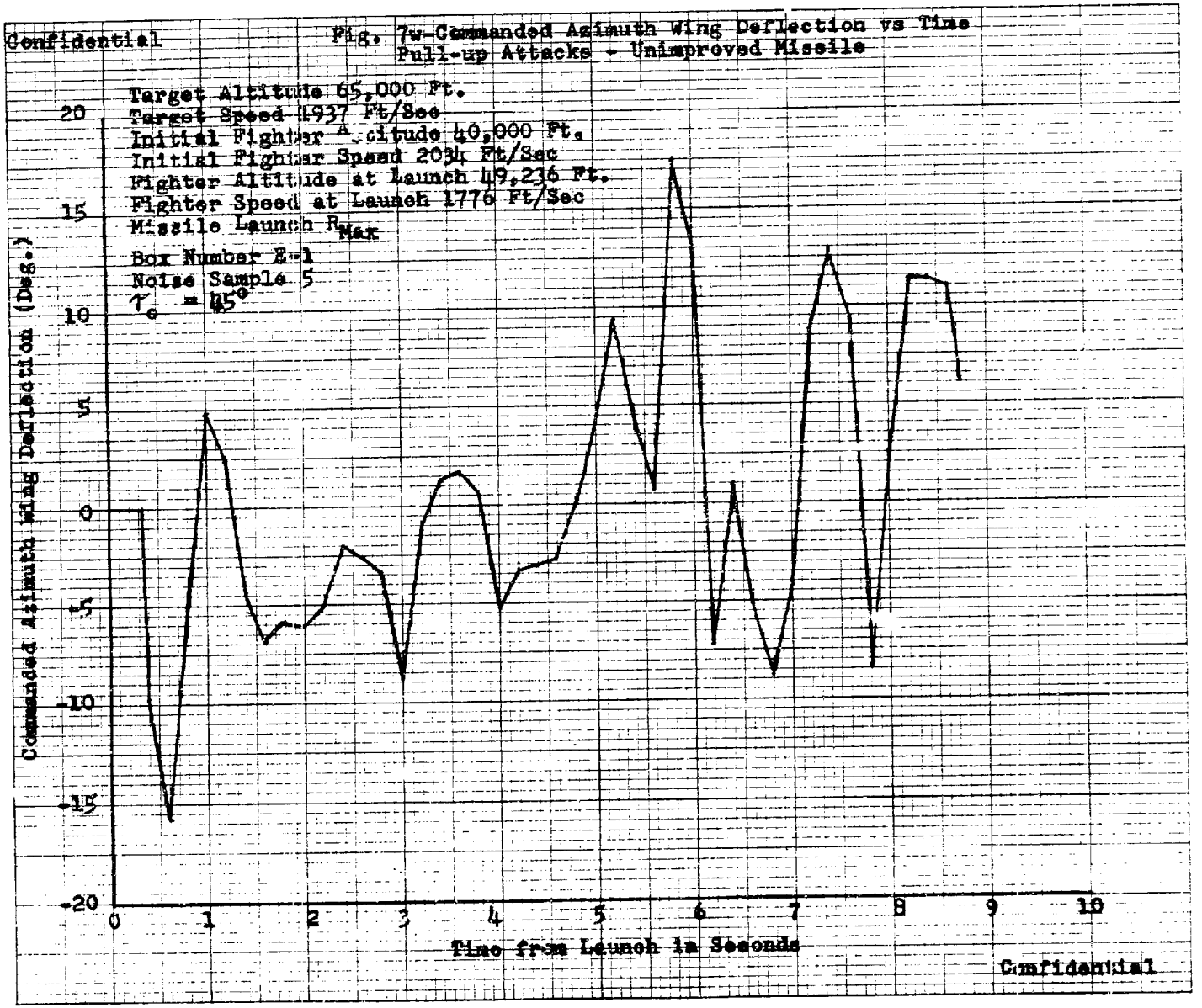

Fig. 7x - Deflection of Missile Pitch Wings vs Time
Pull-up Attacks - Unimproved Missile

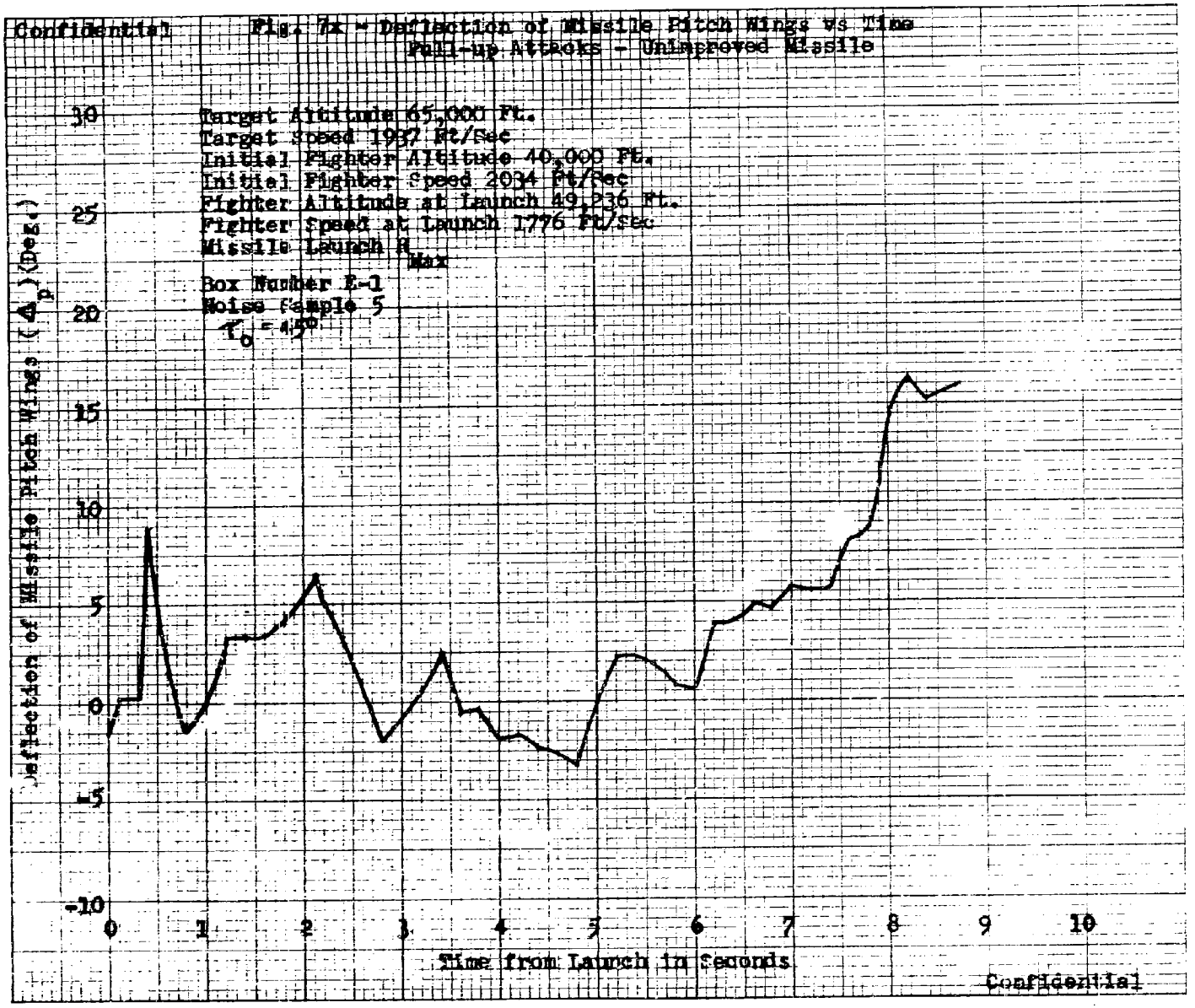

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Fig. 7y - Deflection of Missile Yaw Wings vs Time
Pull-up Attacks - Unimproved Missile

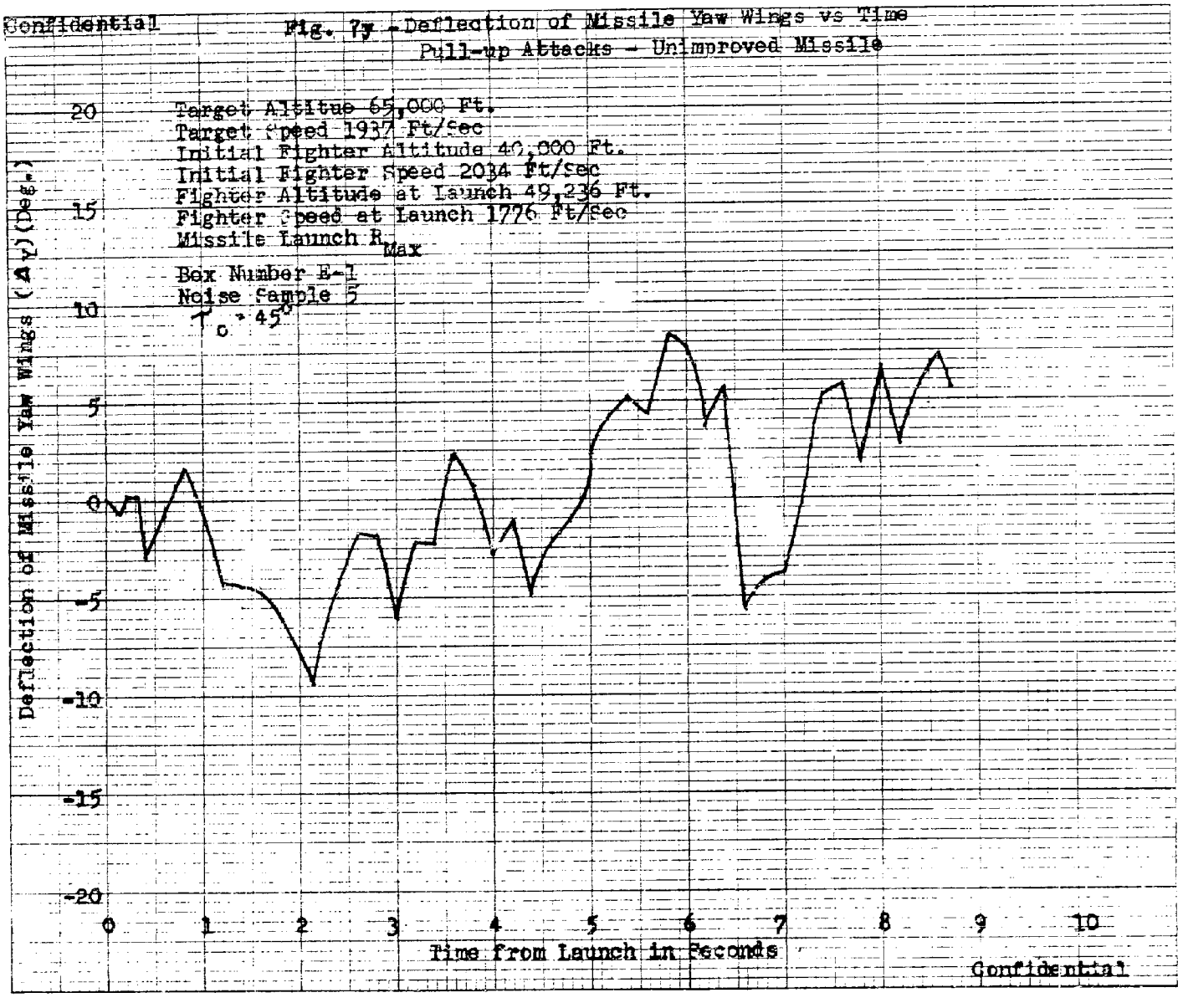

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Fig. 7a - Total Wing Movement vs Time
Pull-up Attacks - Unimproved Missile

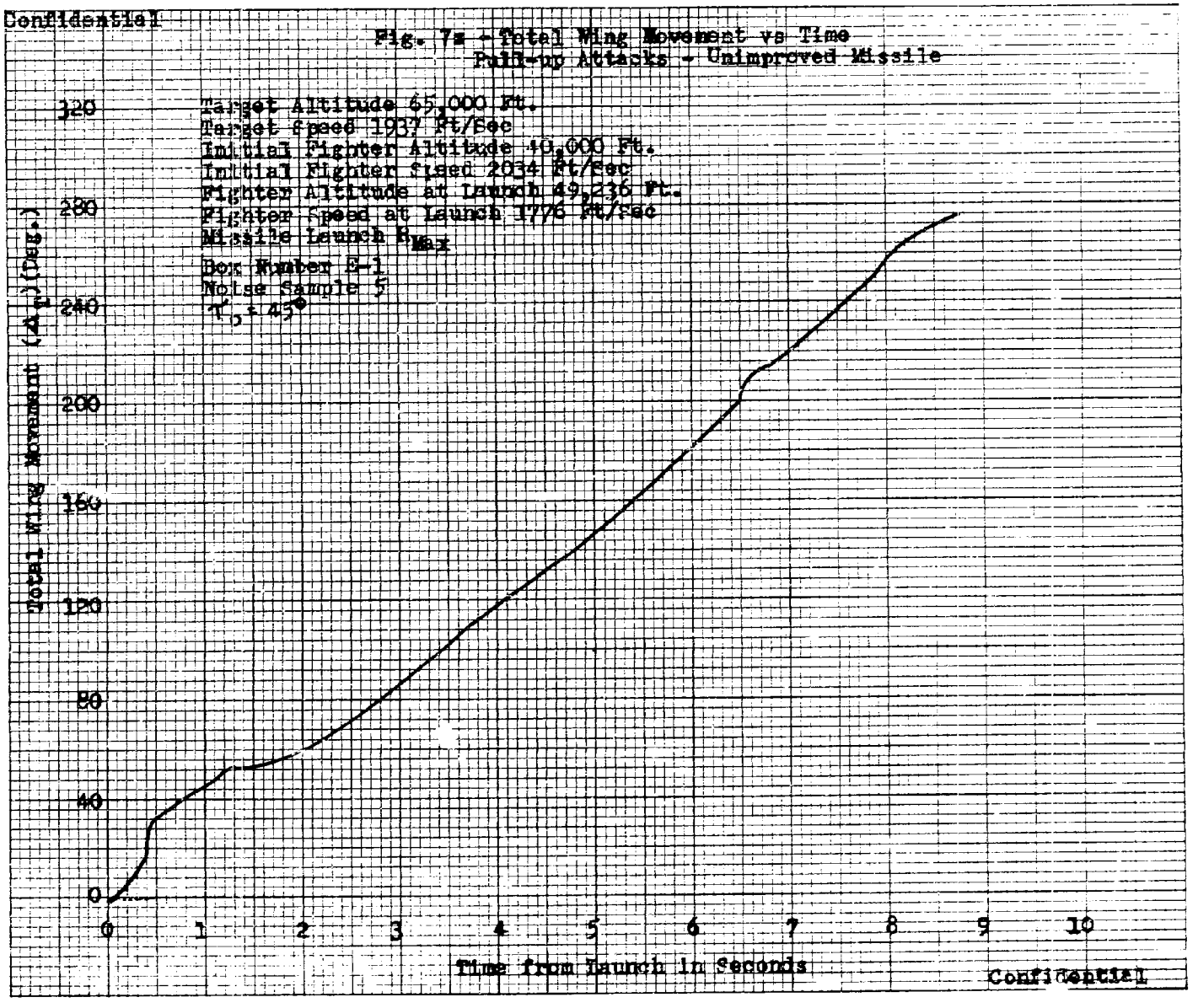

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Fig. 7zz - Missile Altitude vs Time
Pull-up Attacks - Unimproved Missile

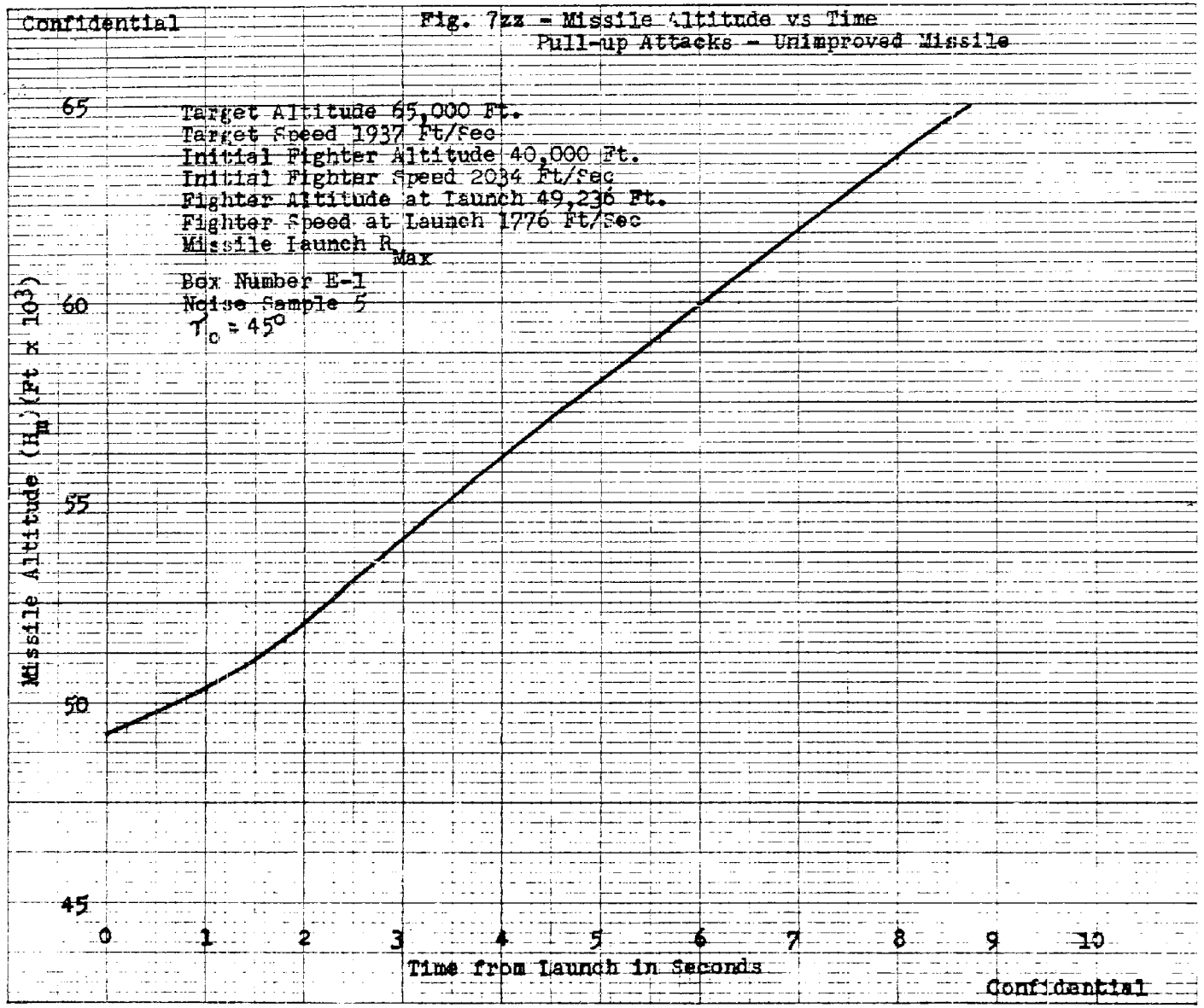

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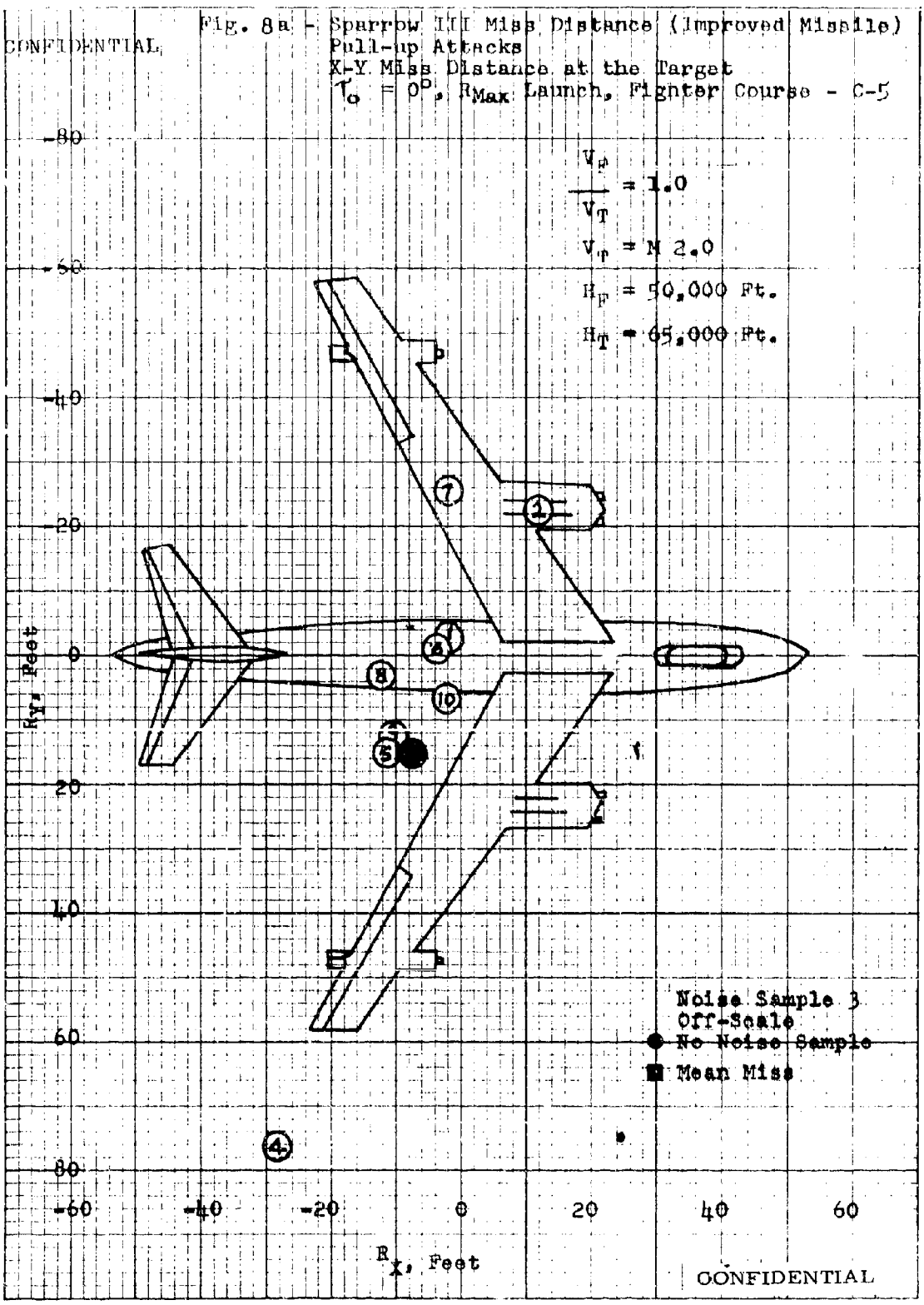
Fig. 8a - Sparrow III Miss Distance (Improved Missile)
Pull-up Attacks
X-Y Miss Distance at the Target
$\tau_o = 0^D$, R_{Max} Launch, Fighter Course - C-5



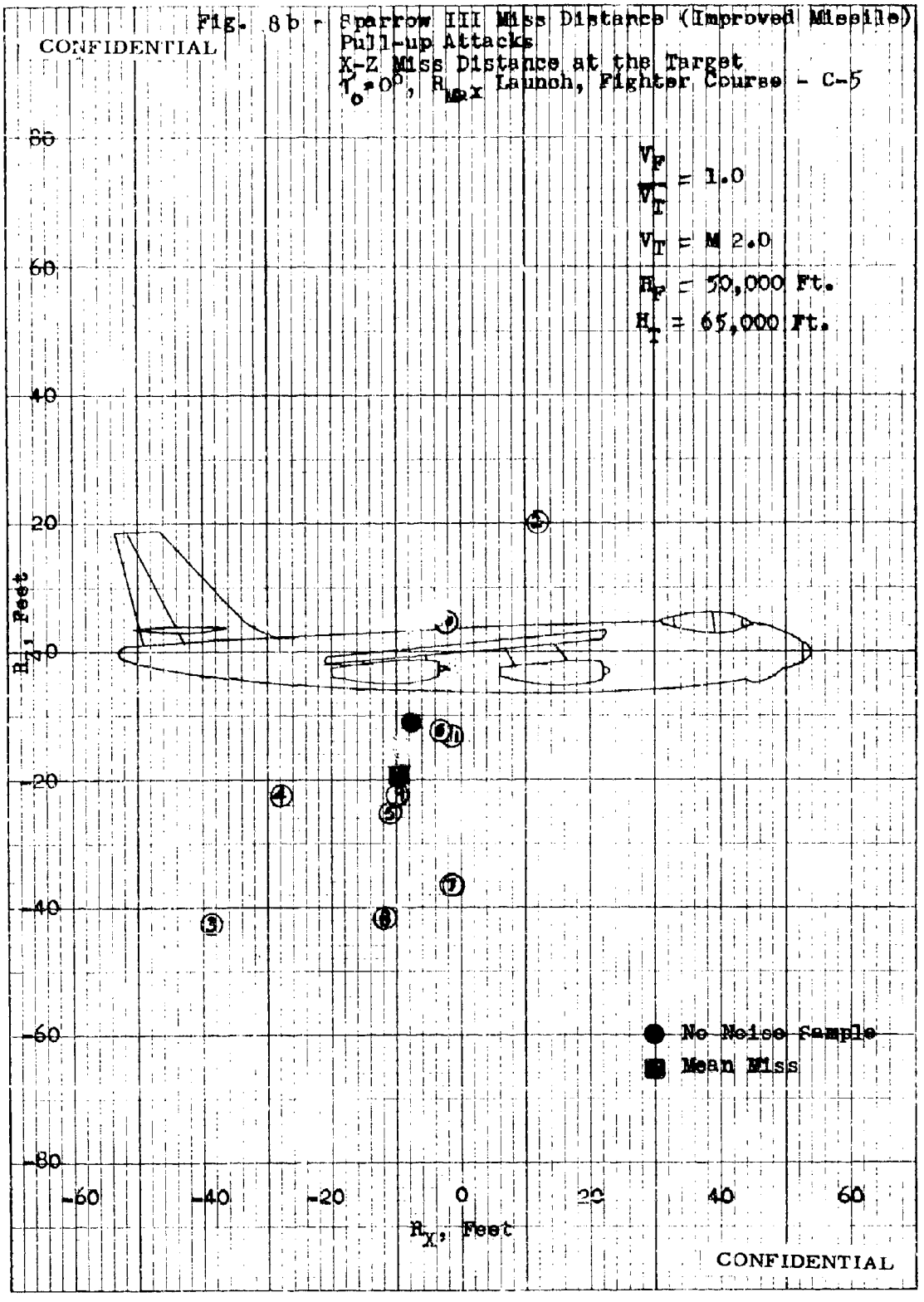


Fig. 8 c- Sparrow III Miss Distance (Improved Missile)
Pull-up Attacks
Y-Z Miss Distance at the Target
$\gamma_o = 0°$, R_{Max} Launch, Fighter Course - C-5

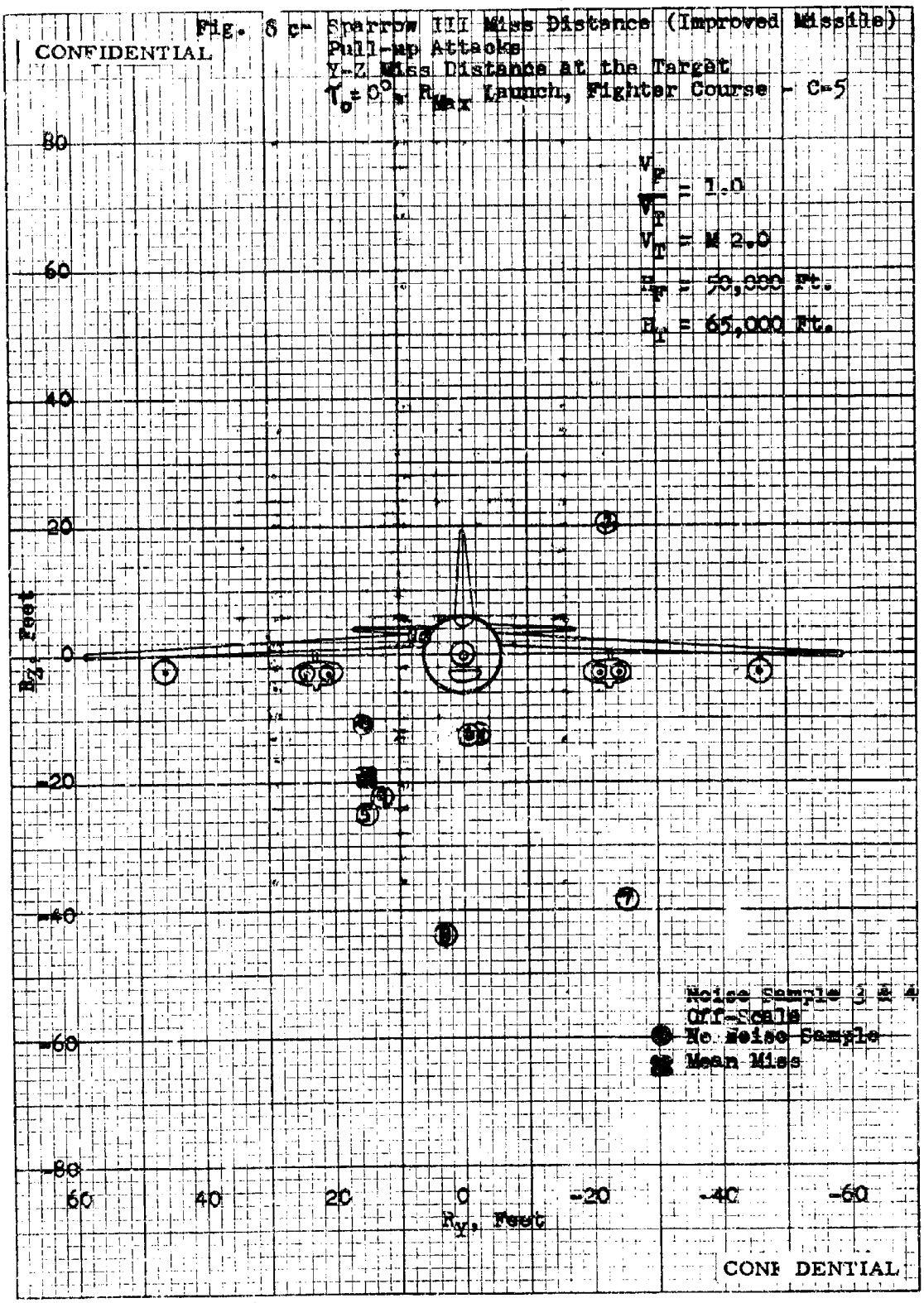


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Fig. 8d - Fighter to Missile Range vs Time
Pull-up Attacks - Improved Missile

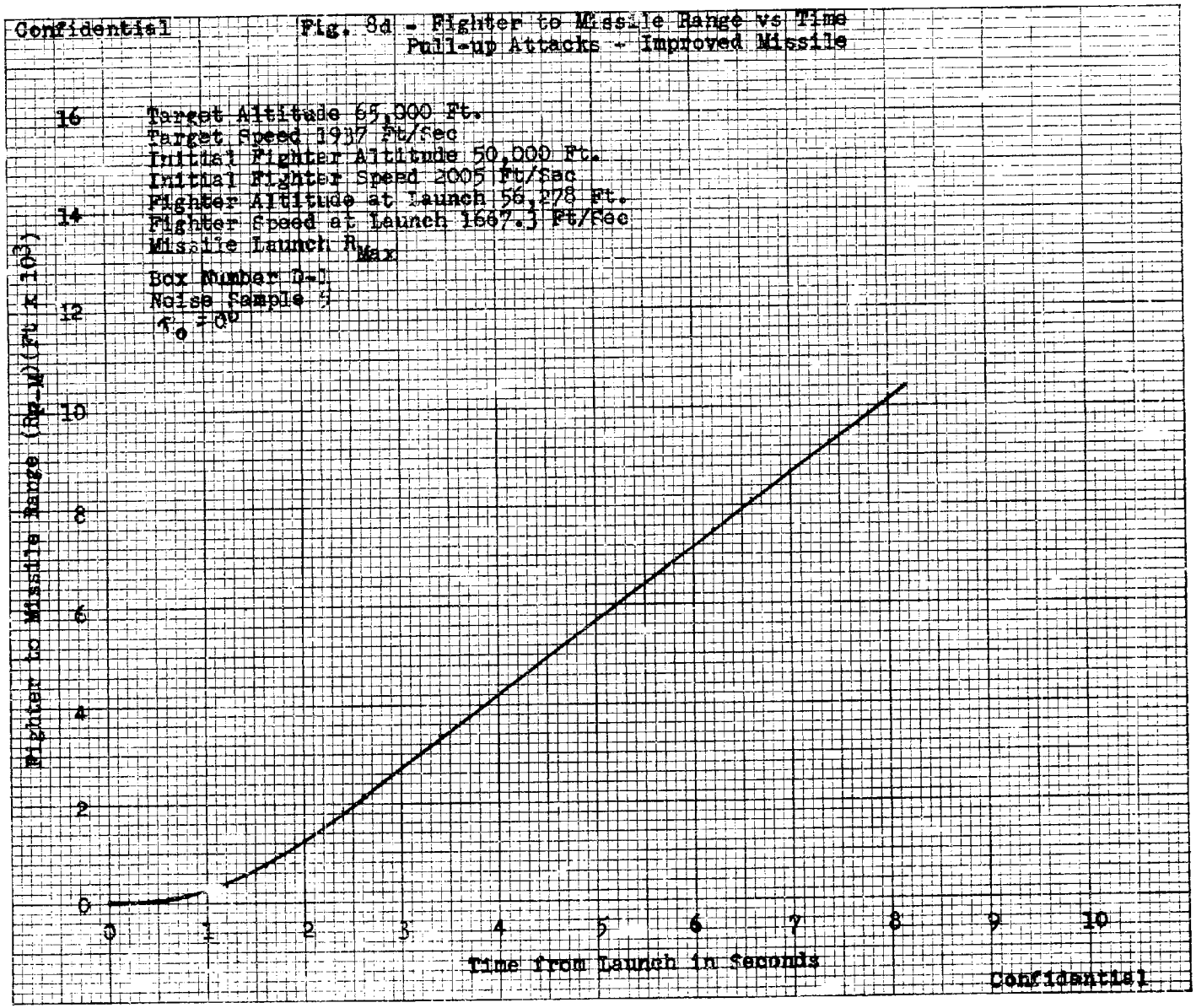

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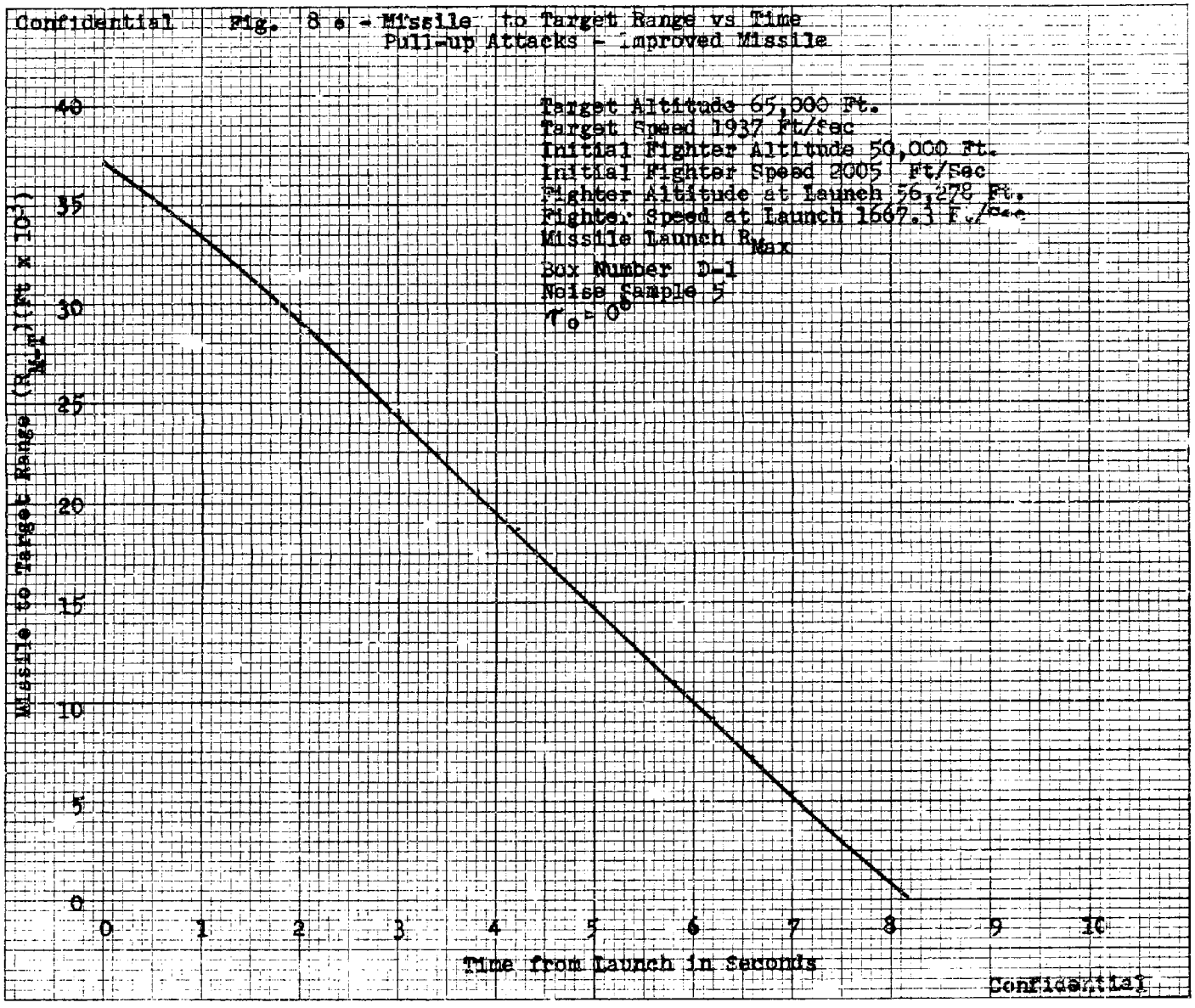
Fig. 8 e - Missile to Target Range vs Time
Pull-up Attacks - Improved Missile



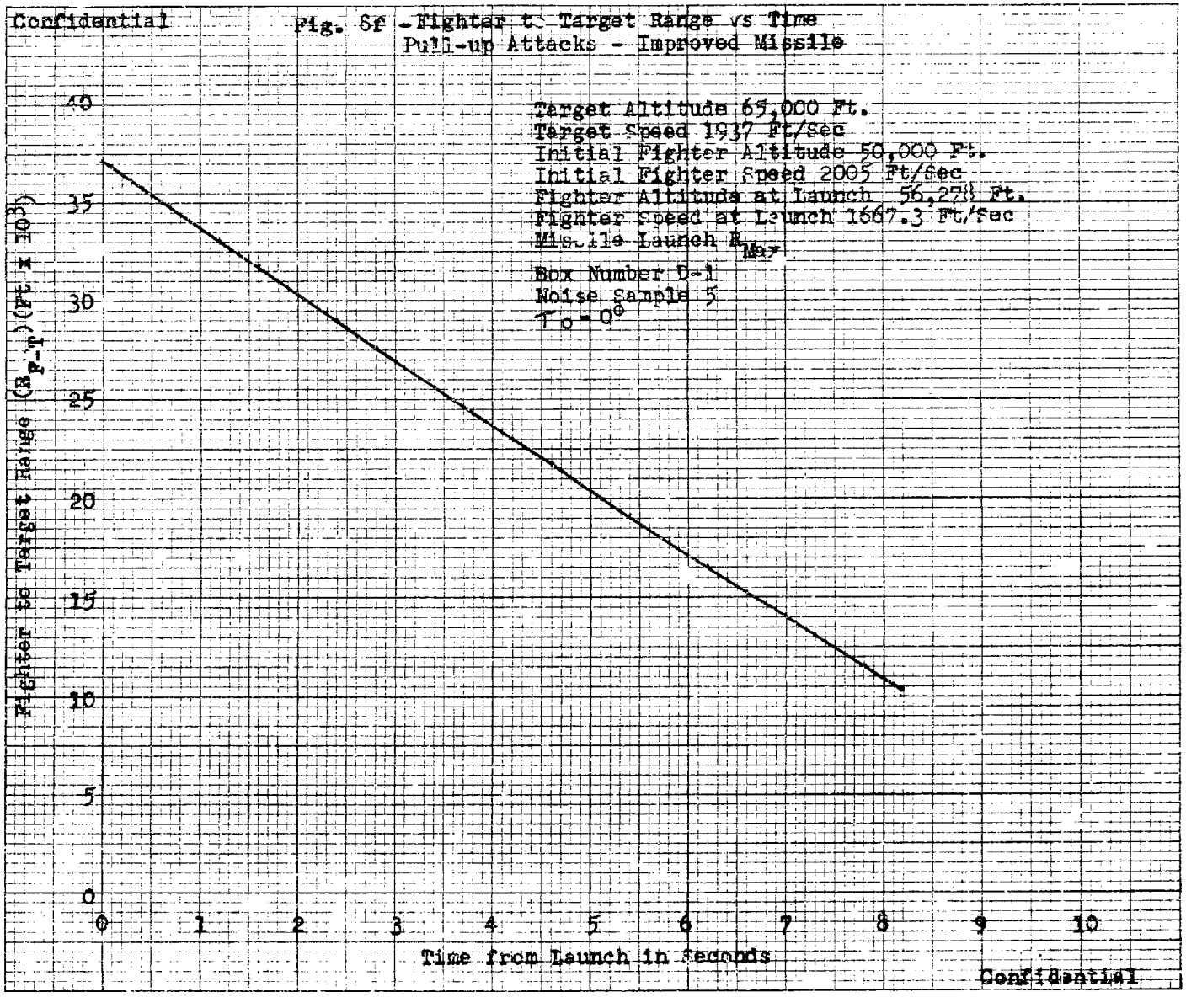
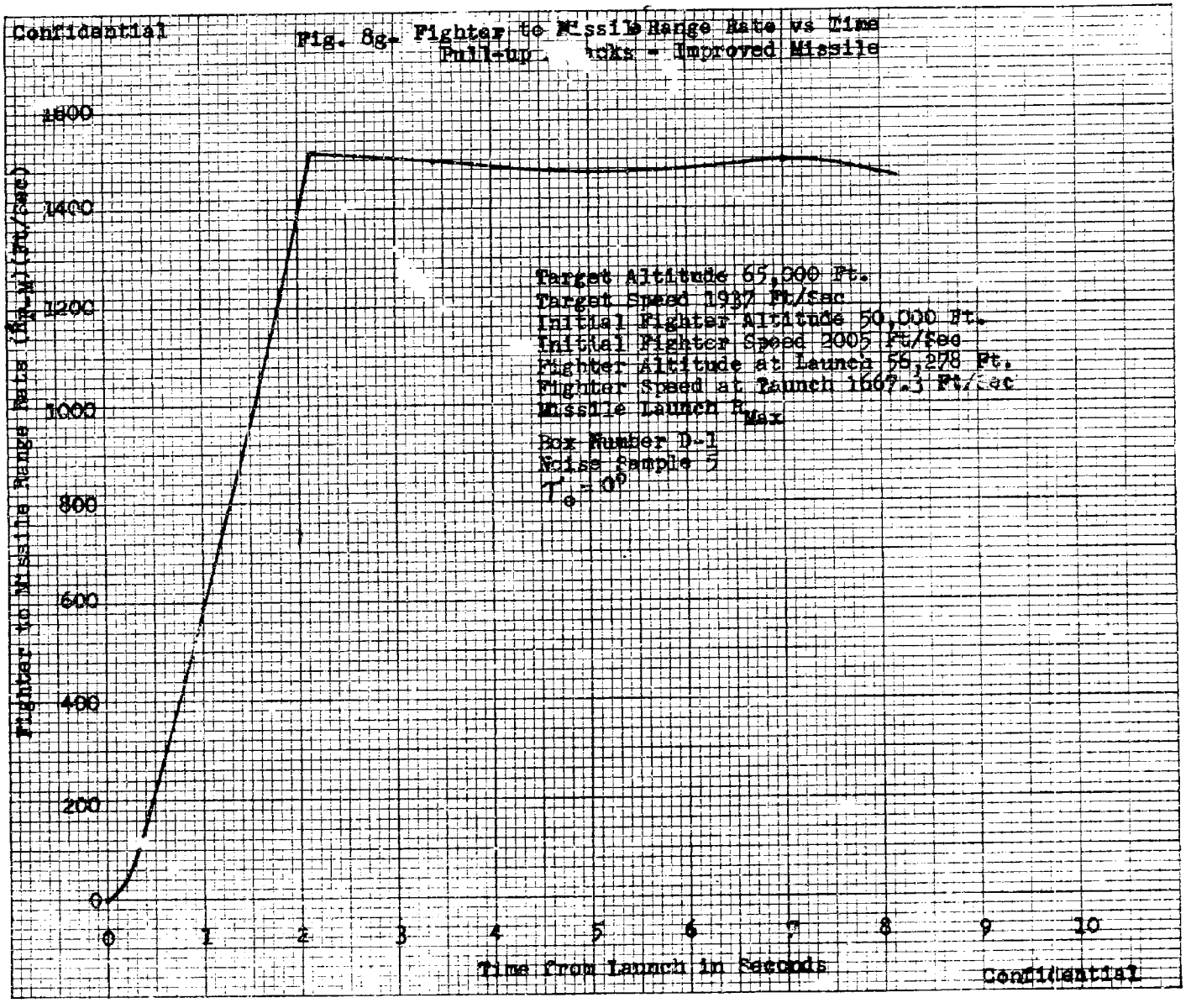


Fig. 8g. Fighter to Missile Range Rate vs Time
Pull-up . nks - Improved Missile



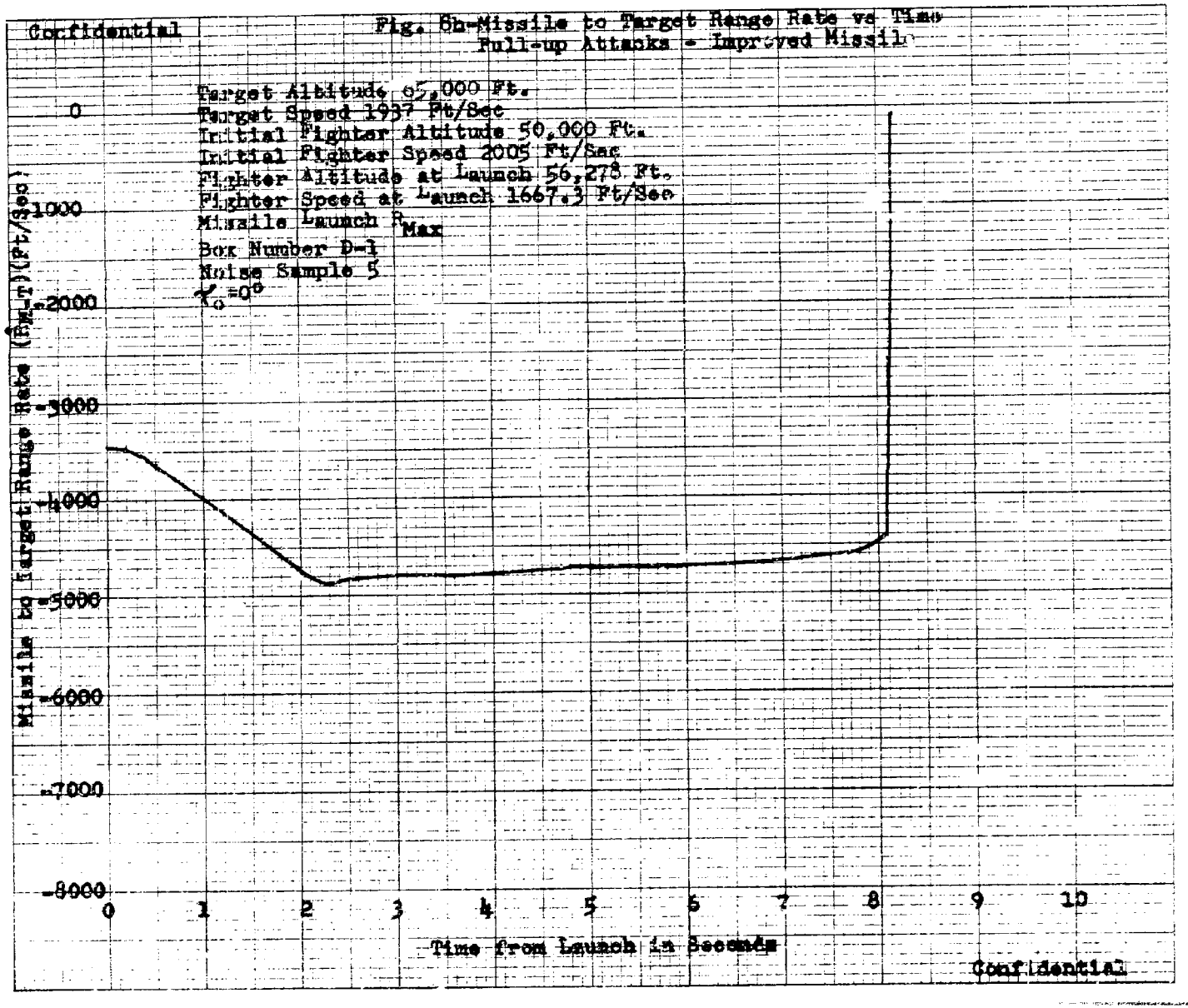


Fig. 81-Fighter to Target Range Rate vs Time
Pull-up Attacks - Impr ved Missile

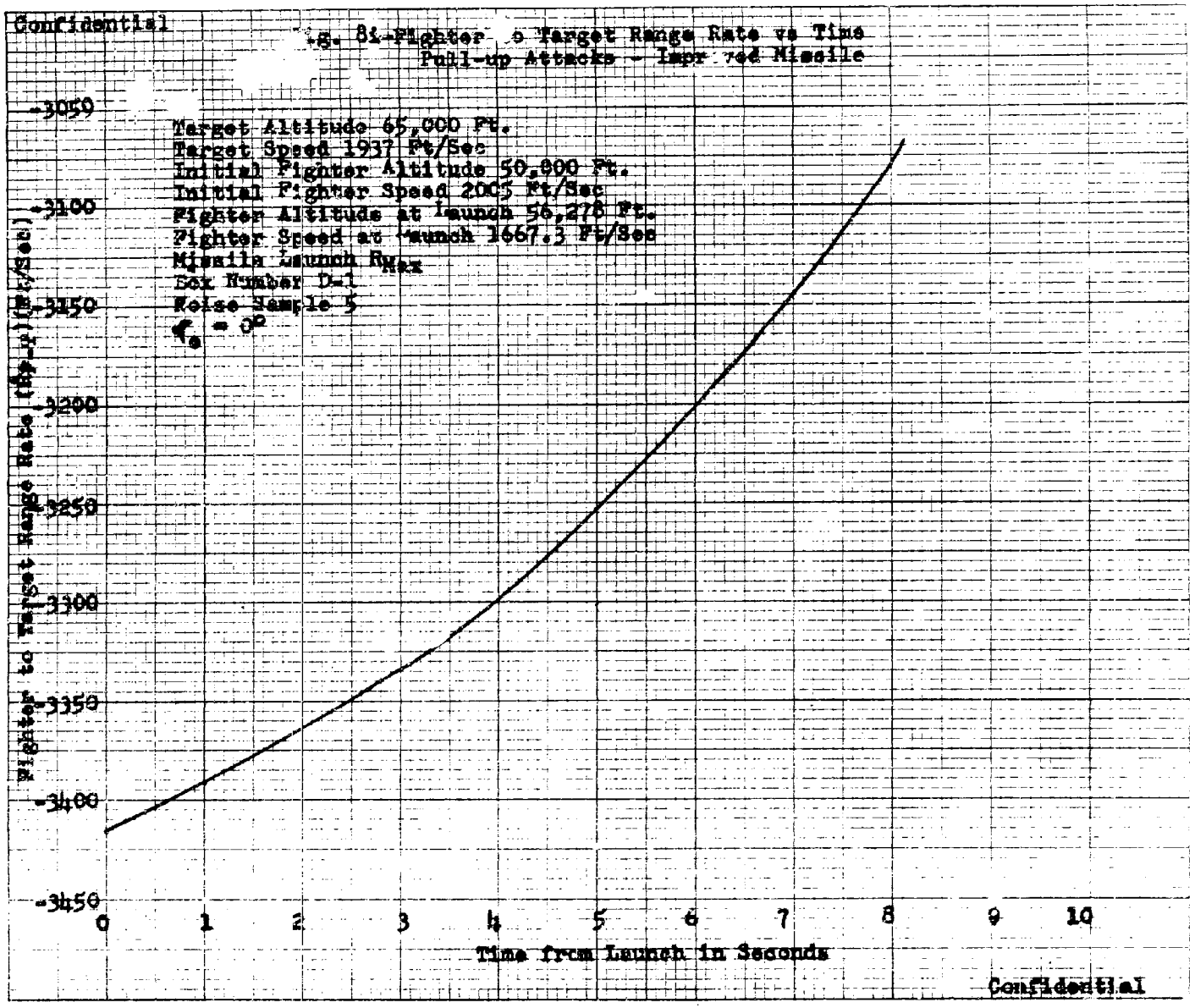


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Fig. 8i-Fighter to Target Range Rate vs Time
Pull-up Attacks - Improved Missile

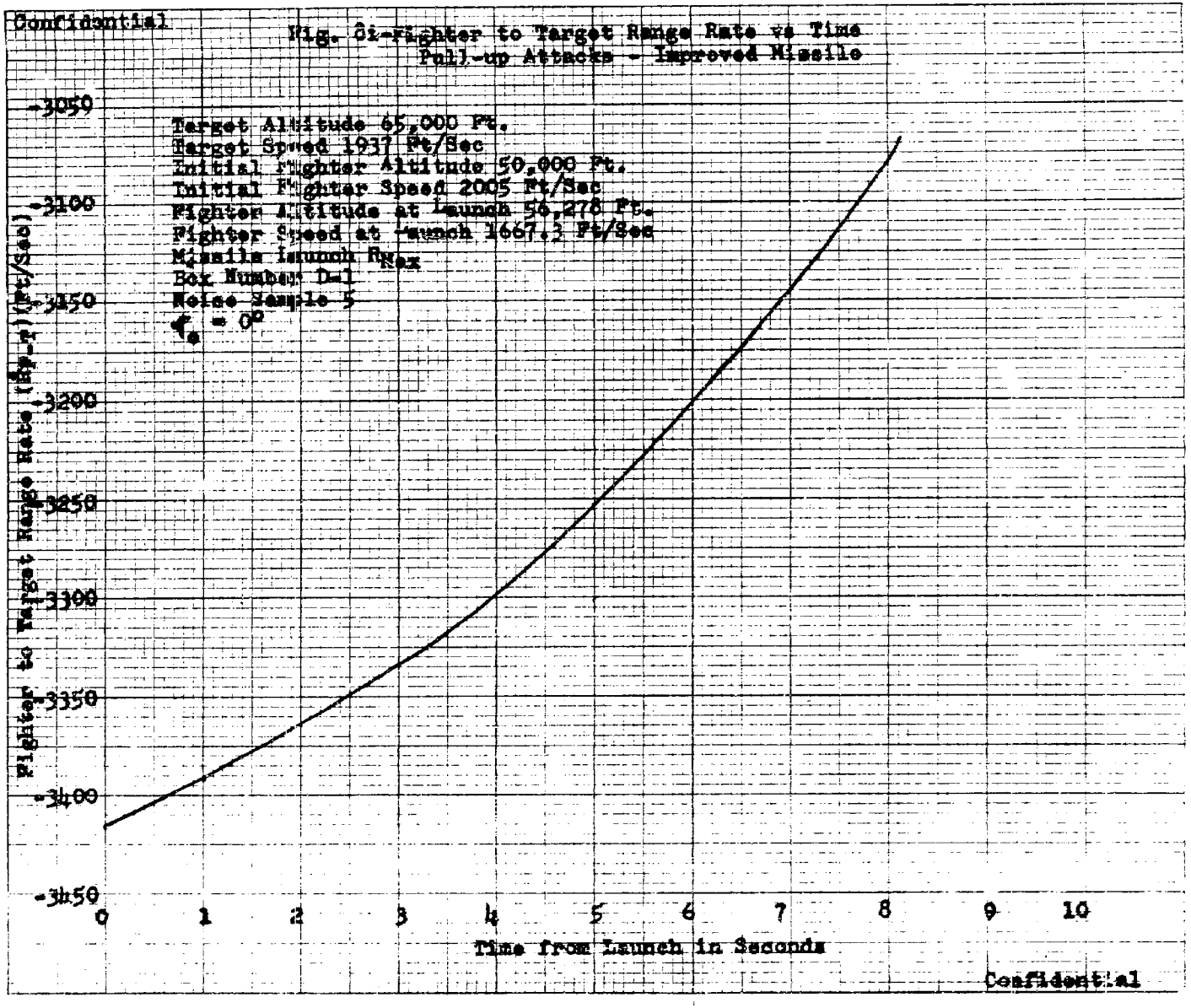

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Fig. 8j -Antenna Azimuth Gimbal Angle of Missile vs Time
Pull-up Attacks - Improved Missile

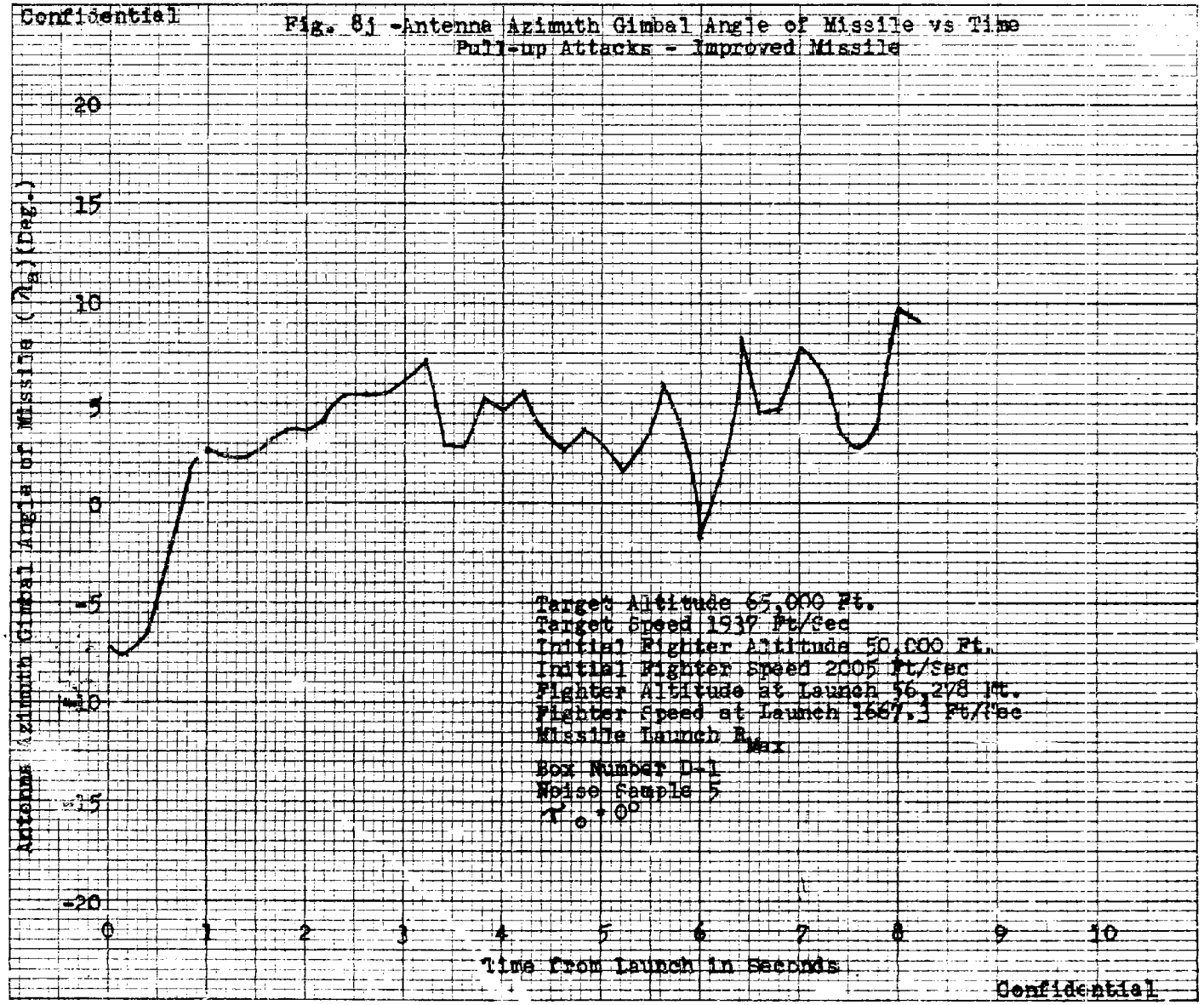

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Fig. 8k - Antenna Elevation Gimbal Angle of Missile vs Time
Pull-up Attacks - Improved Missile

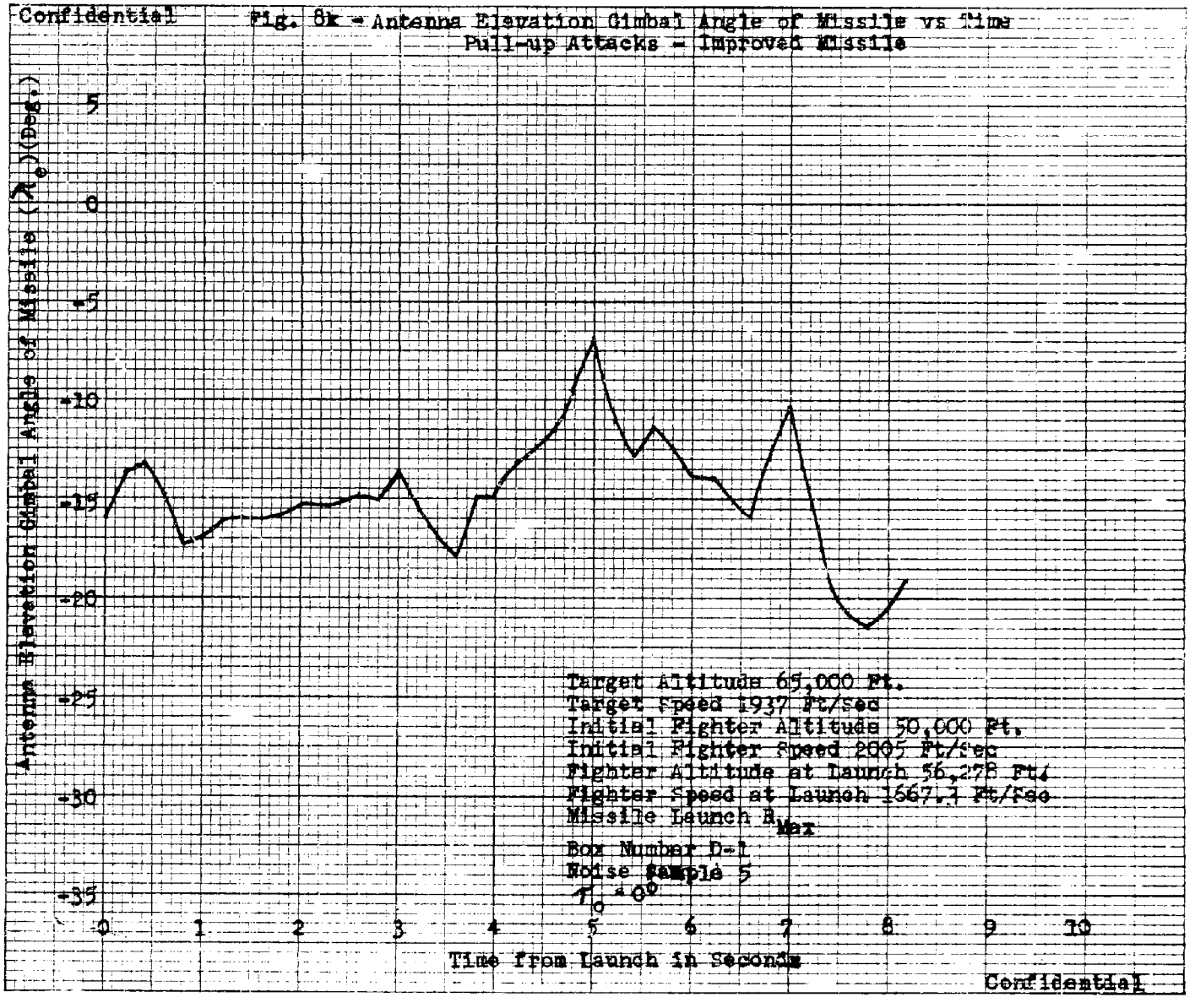

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Fig. 8-1 - Missile Lead Angle vs Time
Pull-up Attacks - Improved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/sec
Initial Fighter Altitude 50,000 Ft.
Initial Fighter Speed 2005 Ft/sec
Fighter Altitude at Launch 56,278 Ft
Fighter Speed at Launch 1667.3 Ft/sec
Missile launch R_{Max}

Box Number D-1
Noise Sample 5
$\tau_o = 0^b$

Missile Lead Angle (λ_M) (Deg.)

23
21
19
17
15
13
11
9
7

0 1 2 3 4 5 6 7 8 9 10

Time from launch in seconds

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Fig. 8 - Azimuth Line of Sight Rate of Missile vs Time
Pull-up Attacks - Improved Missile

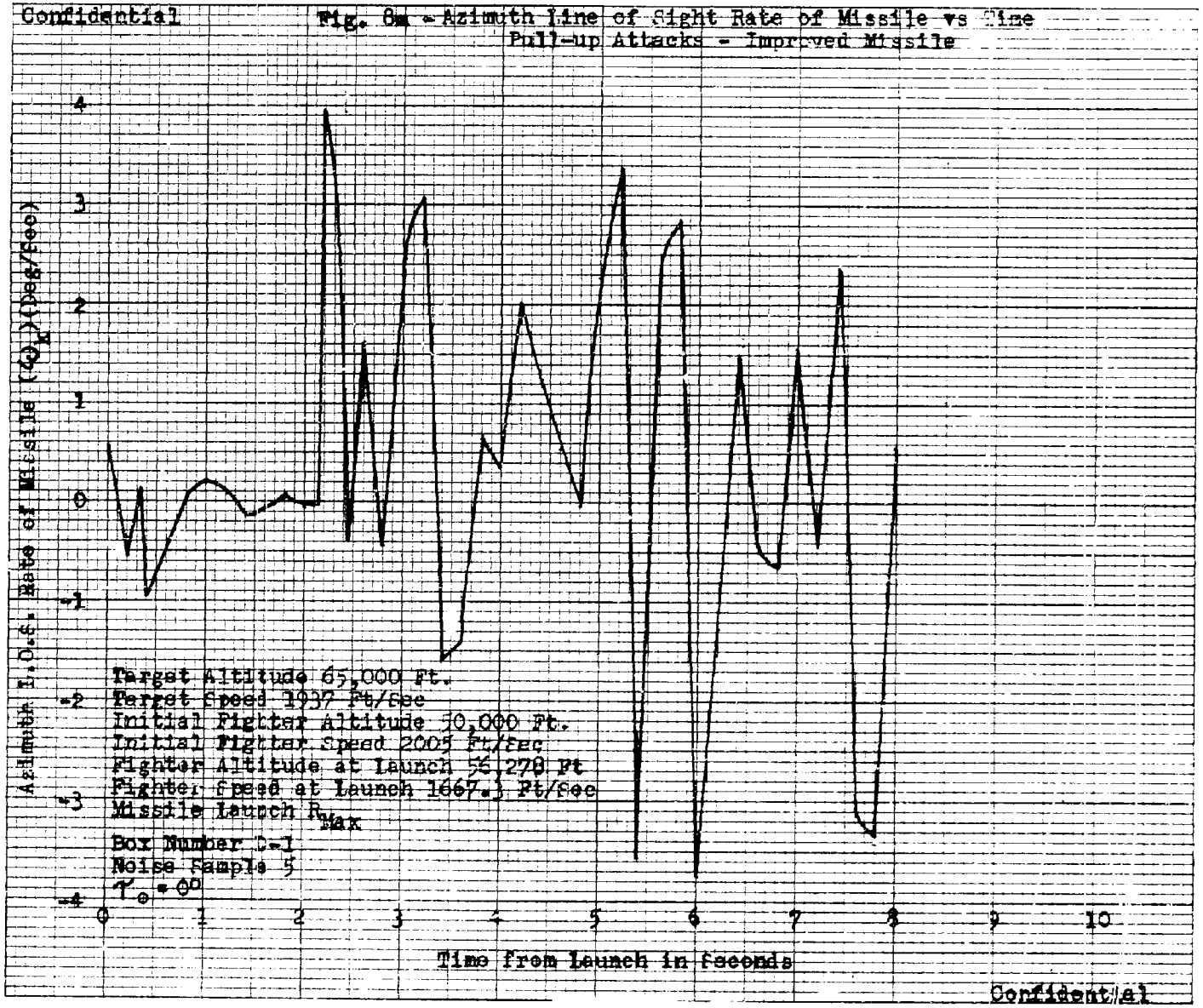

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Fig. 8n - Elevation Line of Sight Rate of Missile vs Time
Pull-up Attacks - Improved Missile

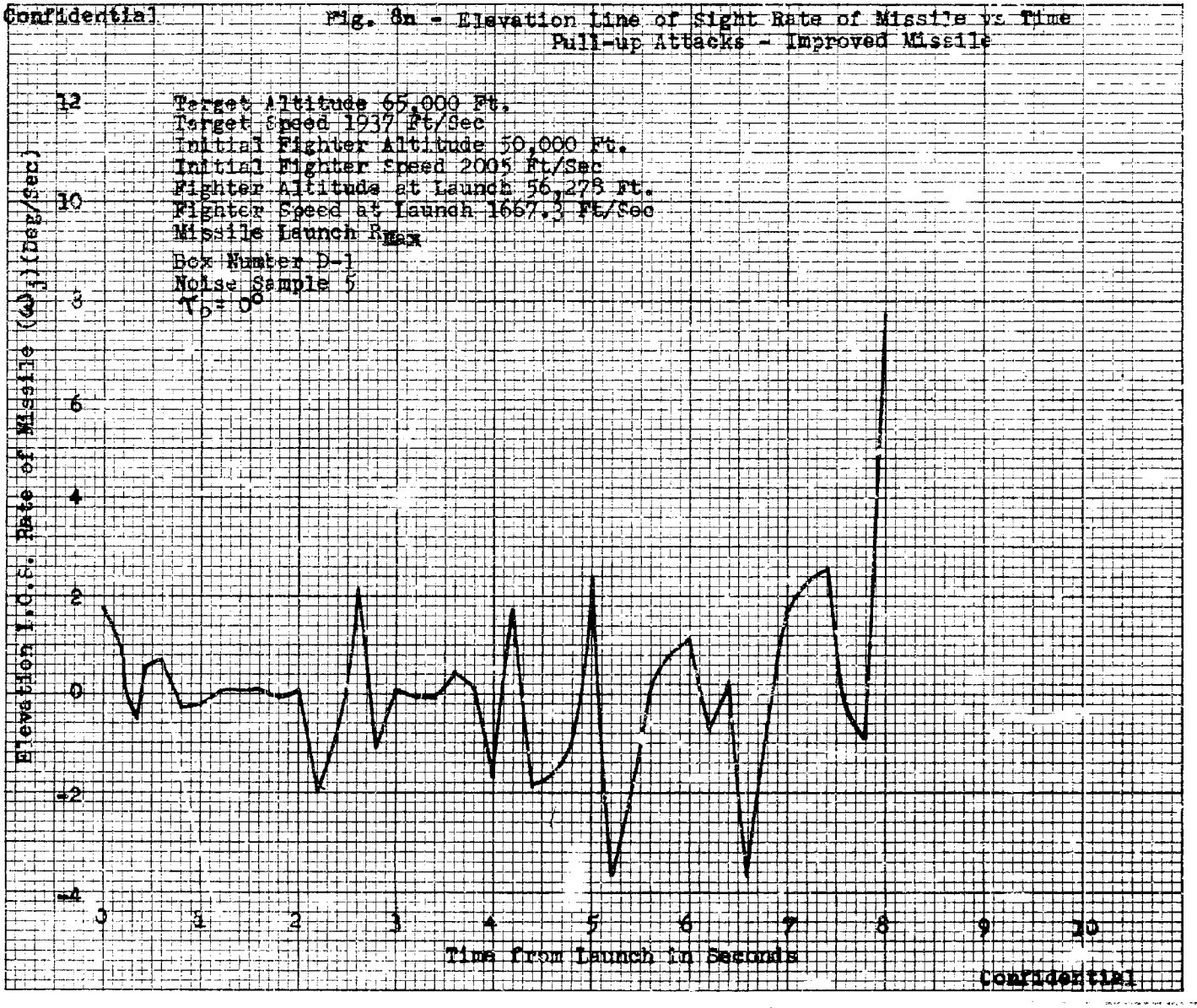

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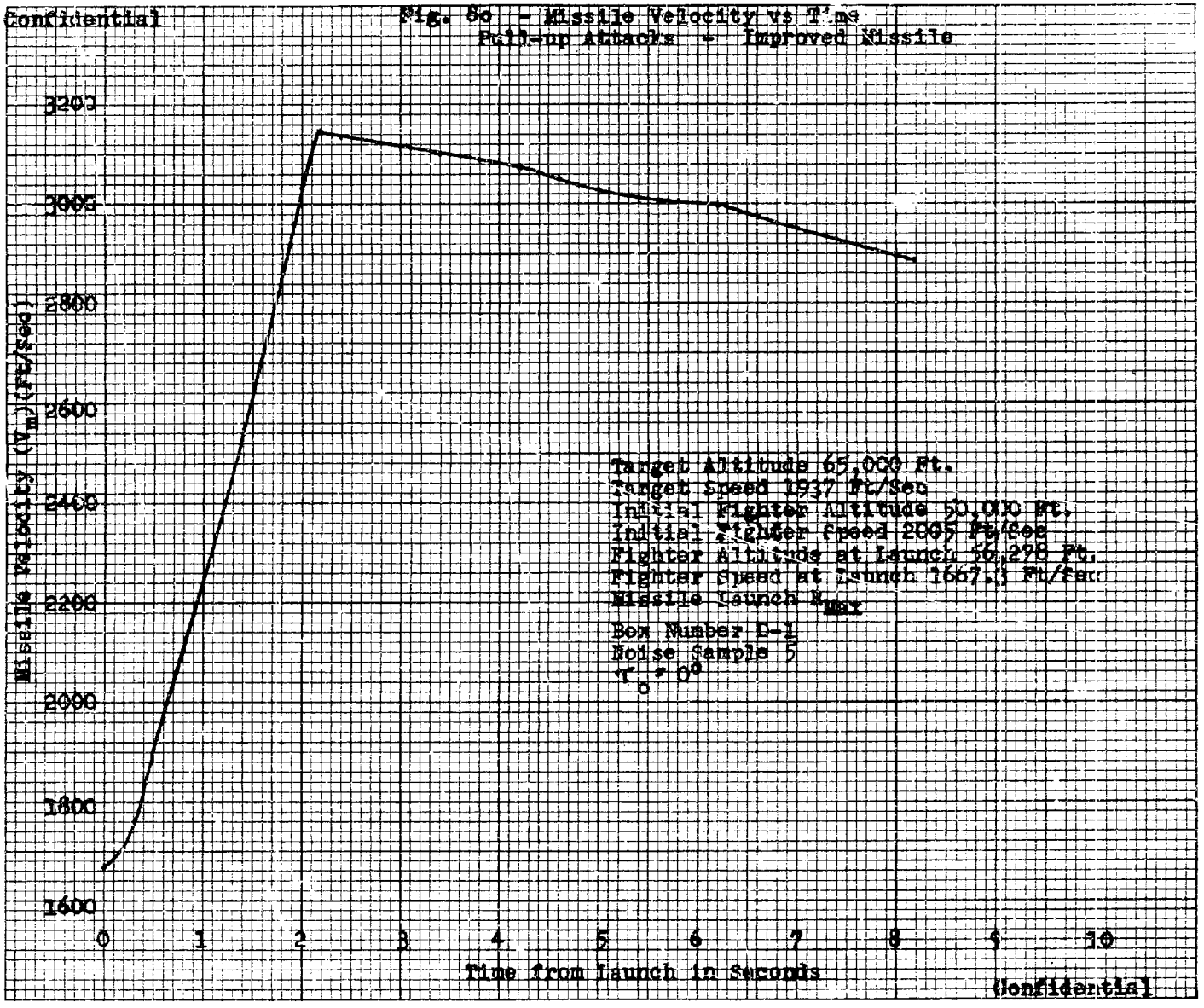
Fig. 8c - Missile Velocity vs T'm
Pull-up Attacks - Improved Missile



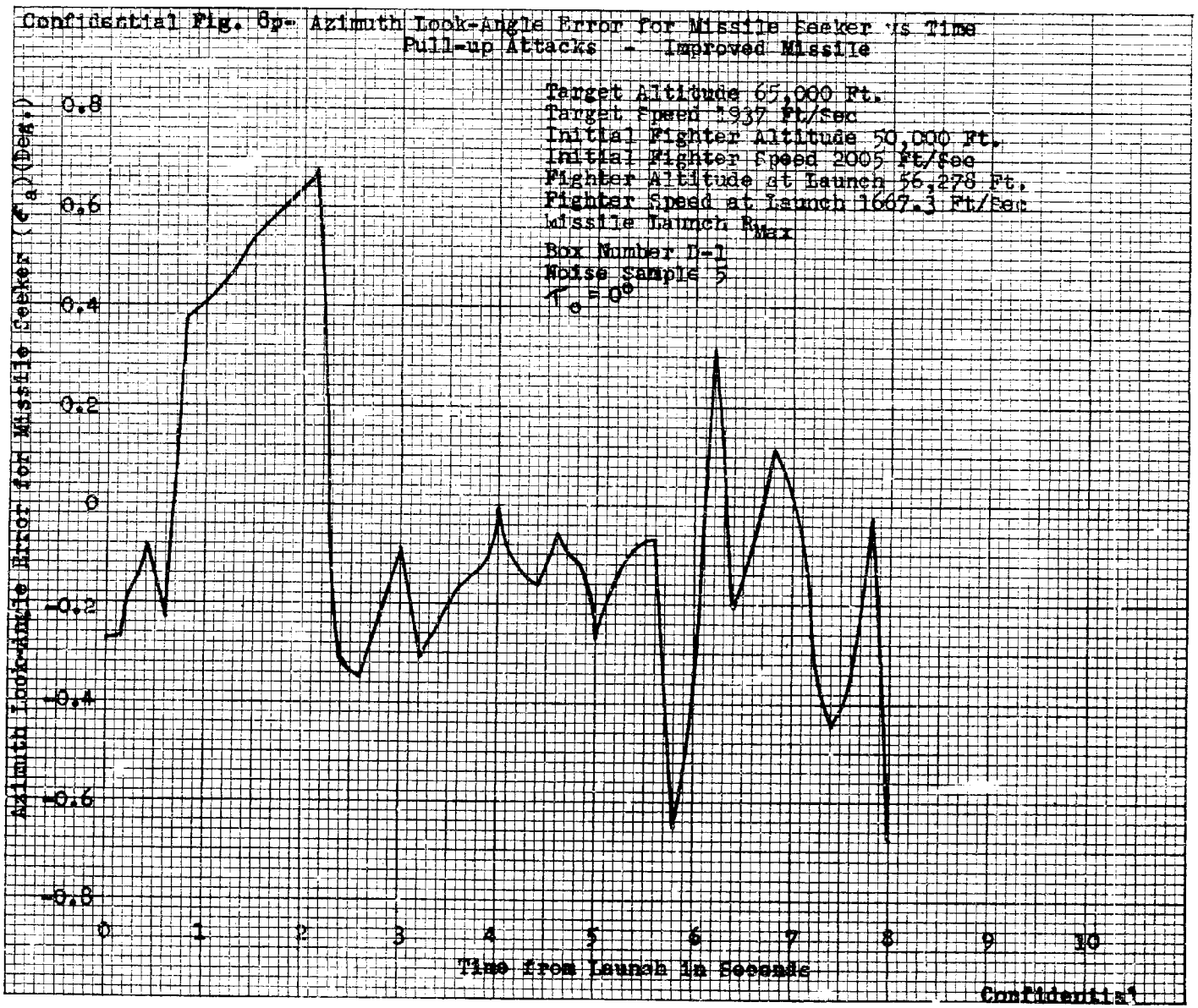


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Fig. 8q - Elevation Look-Angle Error For Missile Seeker vs Time
Pull-up Attack - Improved Missile

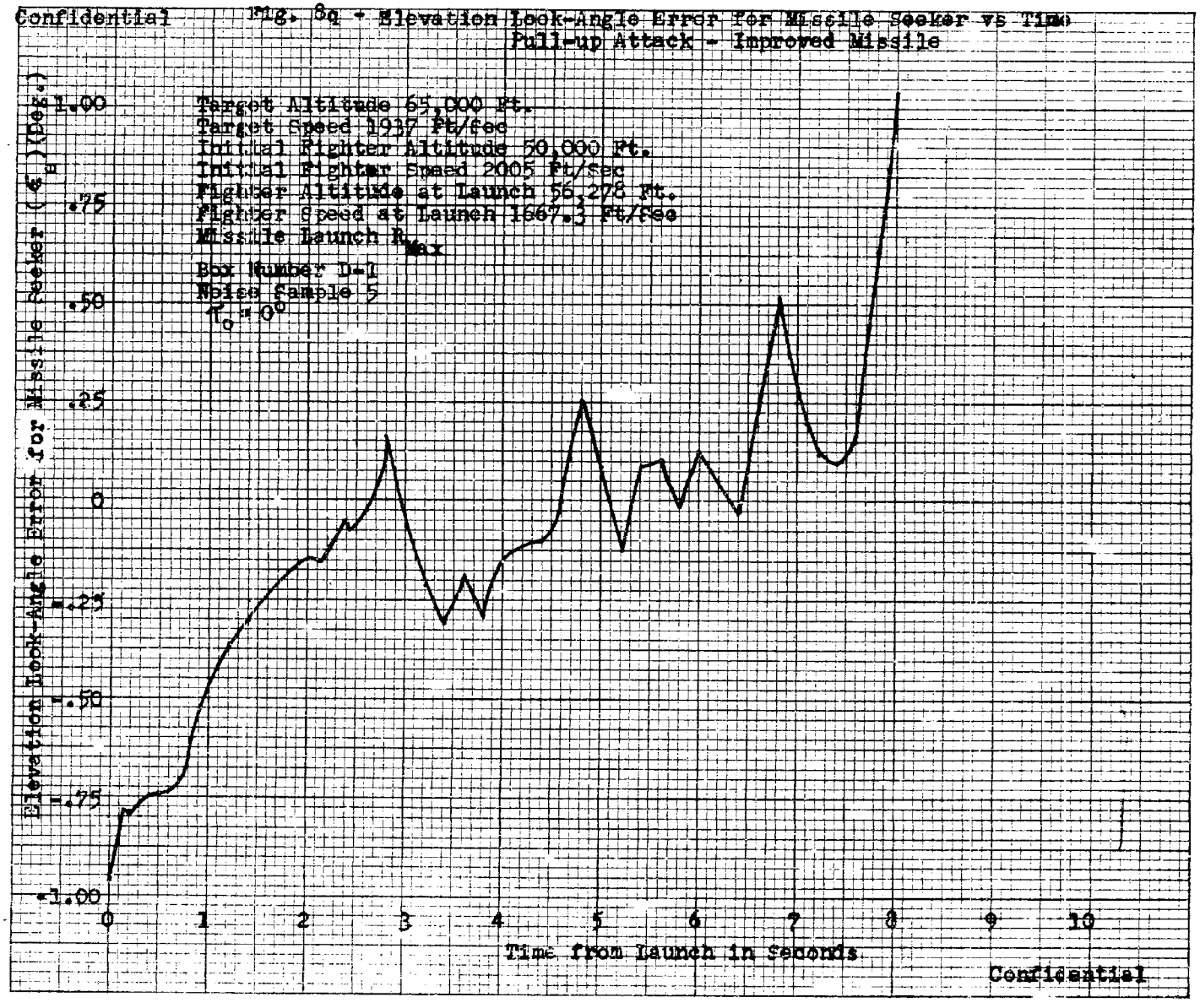

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Fig. 8r - Missile Angle of Attack Vs Time
Pull-up Attack - Improved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 50,000 Ft.
Initial Fighter Speed 2005 Ft/Sec
Fighter Altitude at Launch 56,278 Ft.
Fighter Speed at Launch 1667.3 Ft/Sec
Missile Launch R_{Max}

Box Number D-1
Noise Sample 5
$\alpha_b = 0^0$

Missile Angle of Attack (α) (Deg.)

16
14
12
10
8
6
4
2
0

0 1 2 3 4 5 6 7 8 9 10

Time from Launch in Seconds

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Fig. 8a - Missile and Fighter Roll Angles vs Time
Pull-up Attacks - Improved Missile

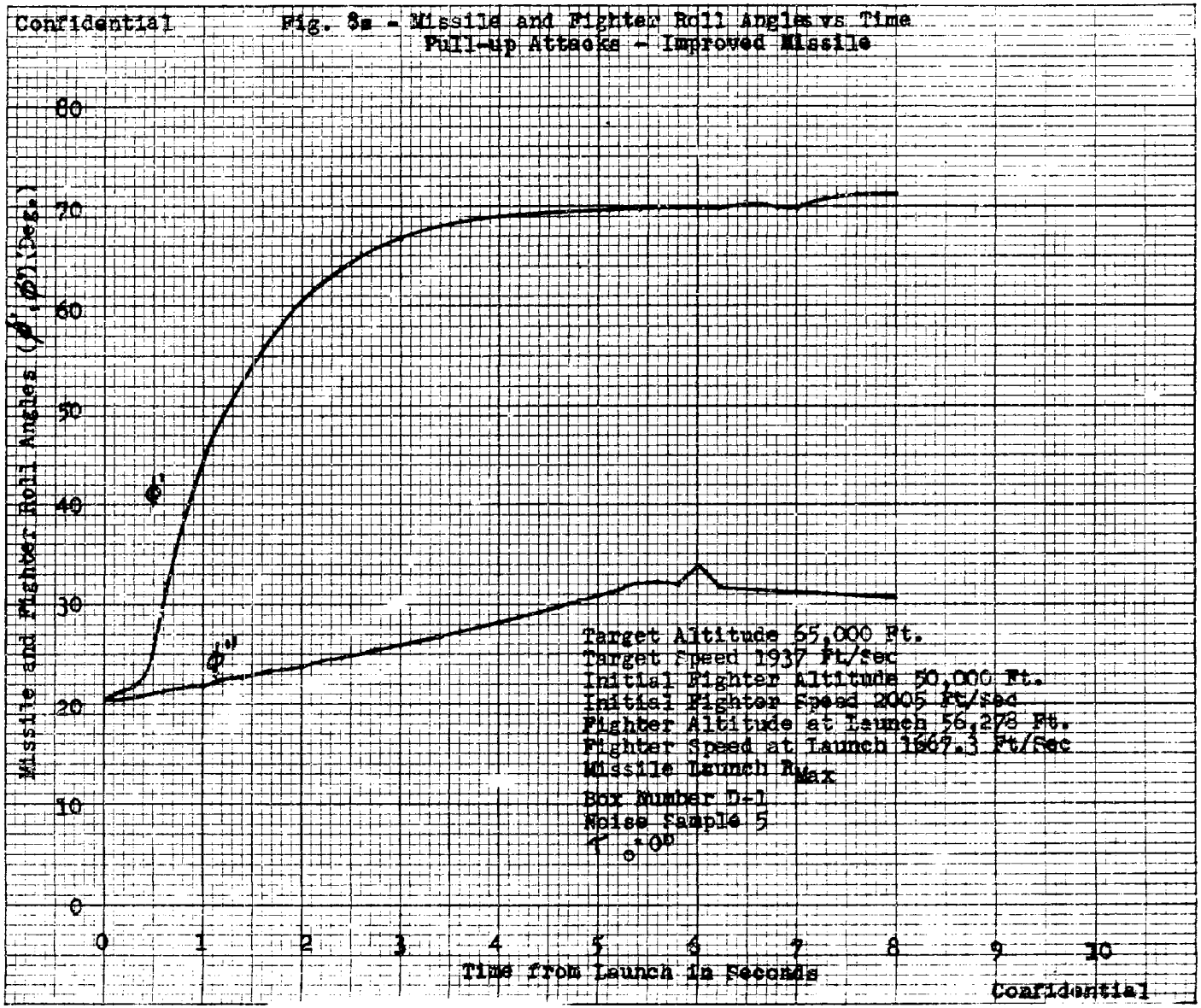

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Fig. 81-Commanded Elevation G's vs Time
Full-up Attacks - Improved Missile

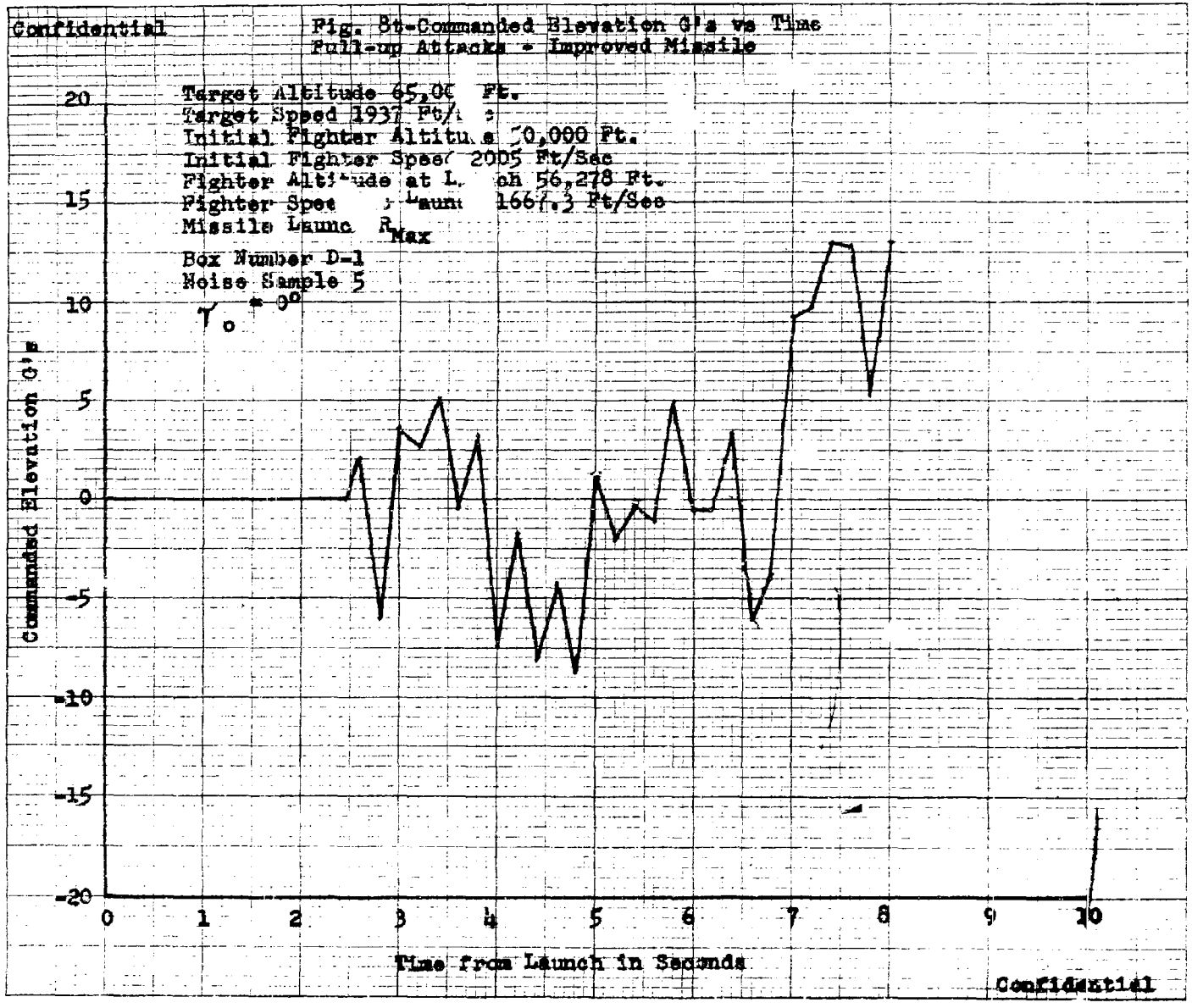

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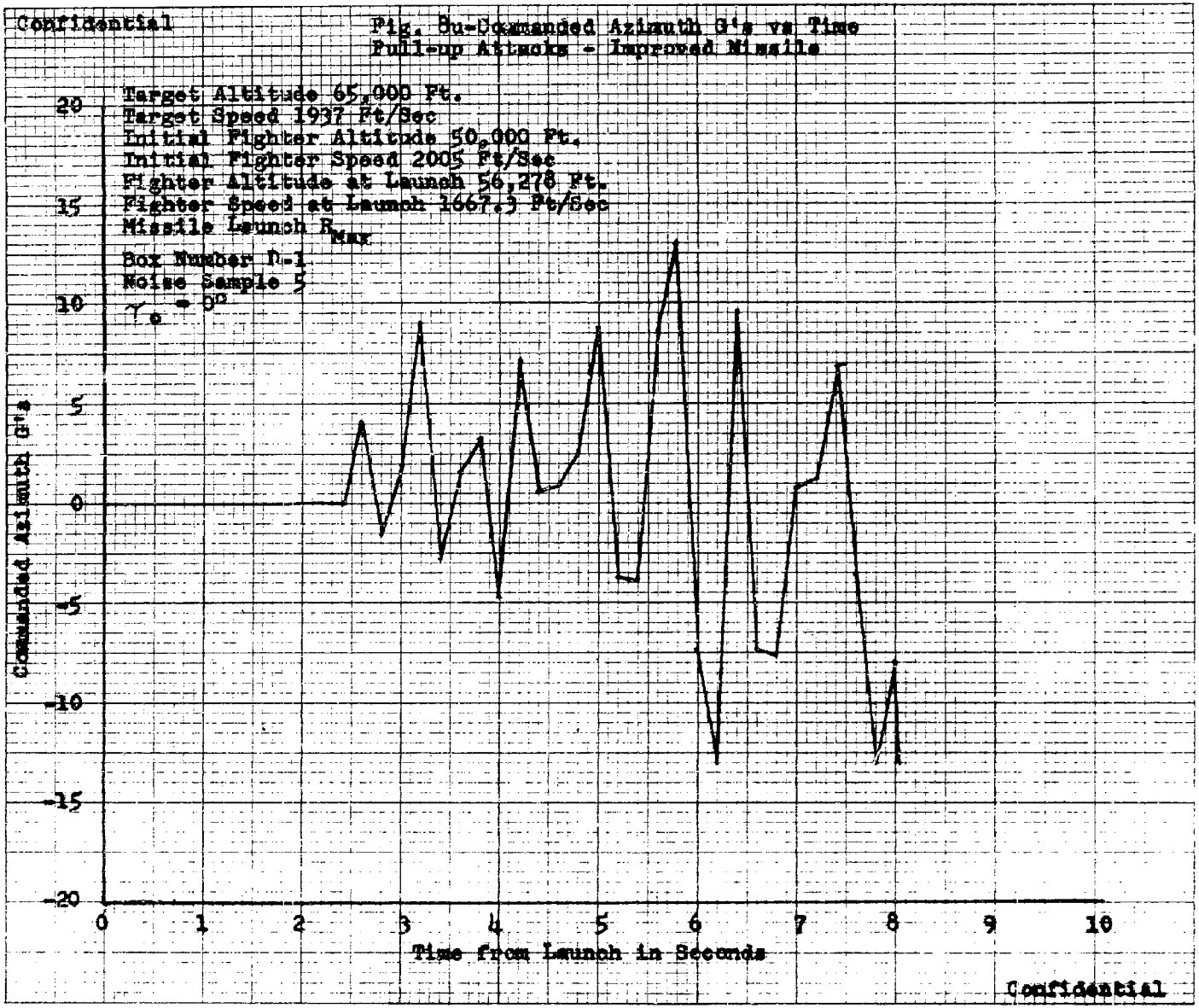
Fig. 8u-Demanded Azimuth G's vs Time
Pull-up Attacks - Improved Missile



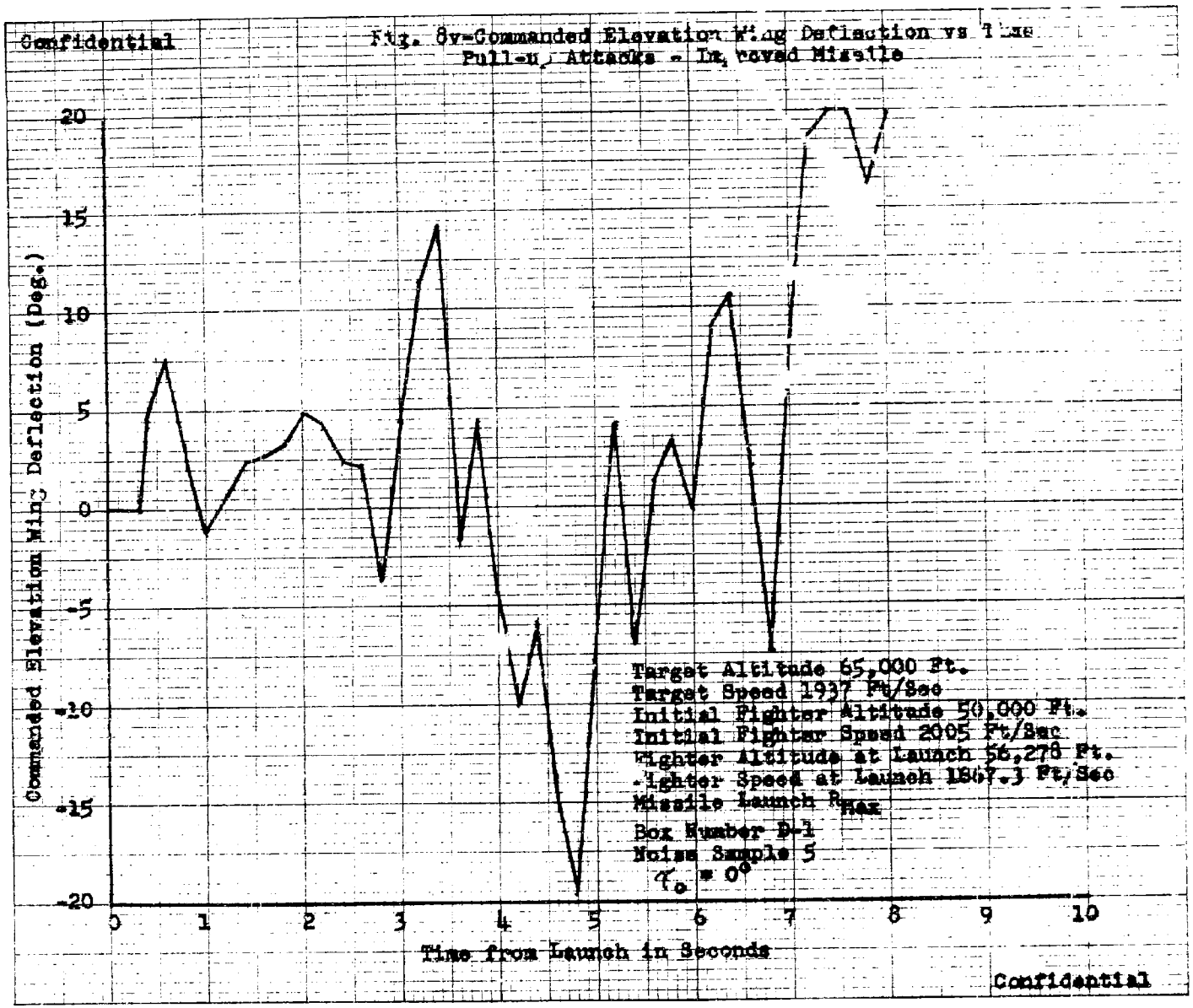


Fig. 8w-Commanded Azimuth Wing Deflection vs Time
Pull-up Attacks - Improved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 50,000 Ft.
Initial Fighter Speed 2005 Ft/Sec
Fighter Altitude at Launch 56,218 Ft.
Fighter Speed at Launch 1667.3 Ft/Sec
Missile Launch R_{Max}
Box Number L-1
Noise Sample 5
$\gamma_c = 0°$

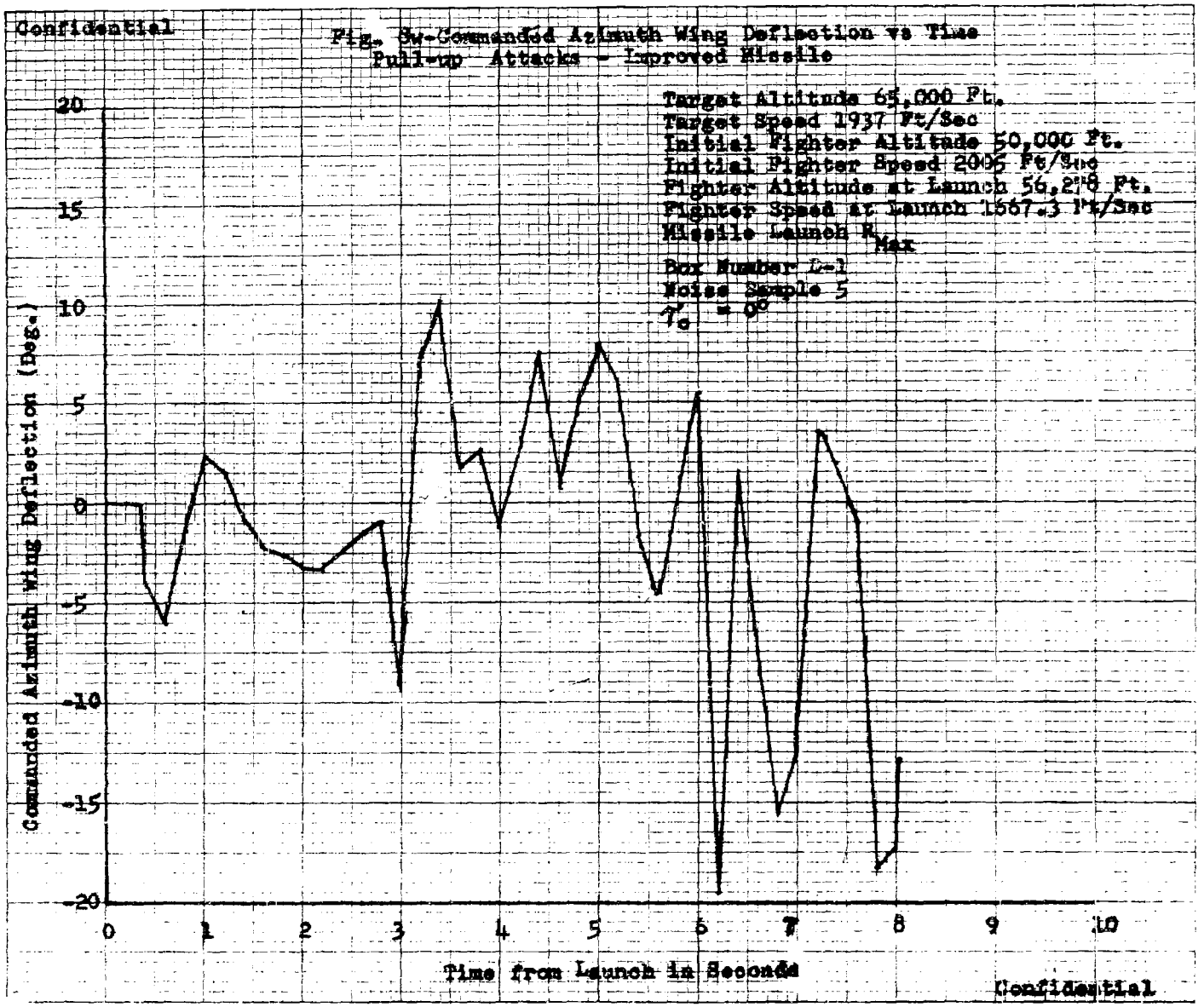


Fig. 8x - Deflection of Missile Pitch Wings vs Time
Pull-up Attack - Improved Missile

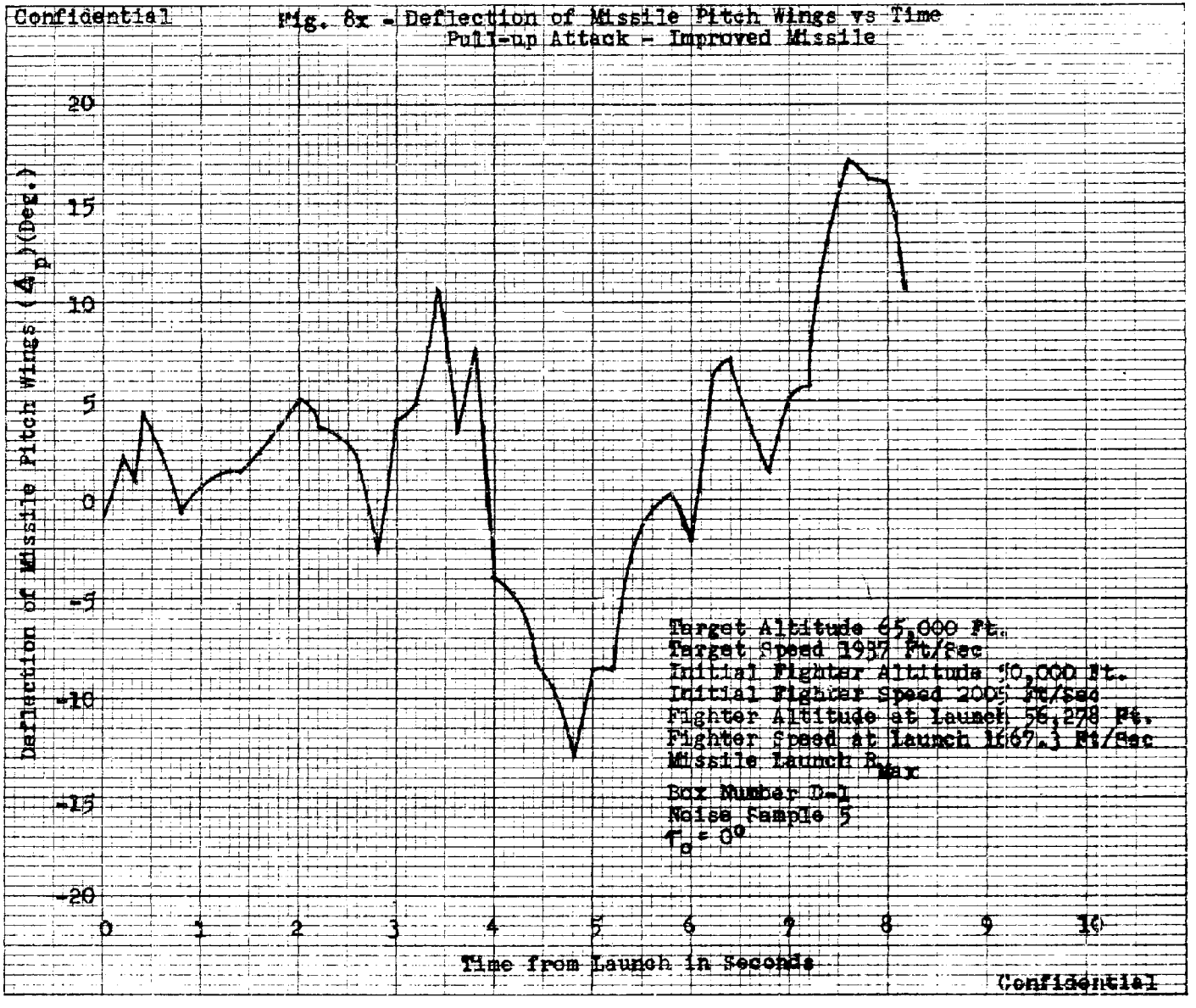
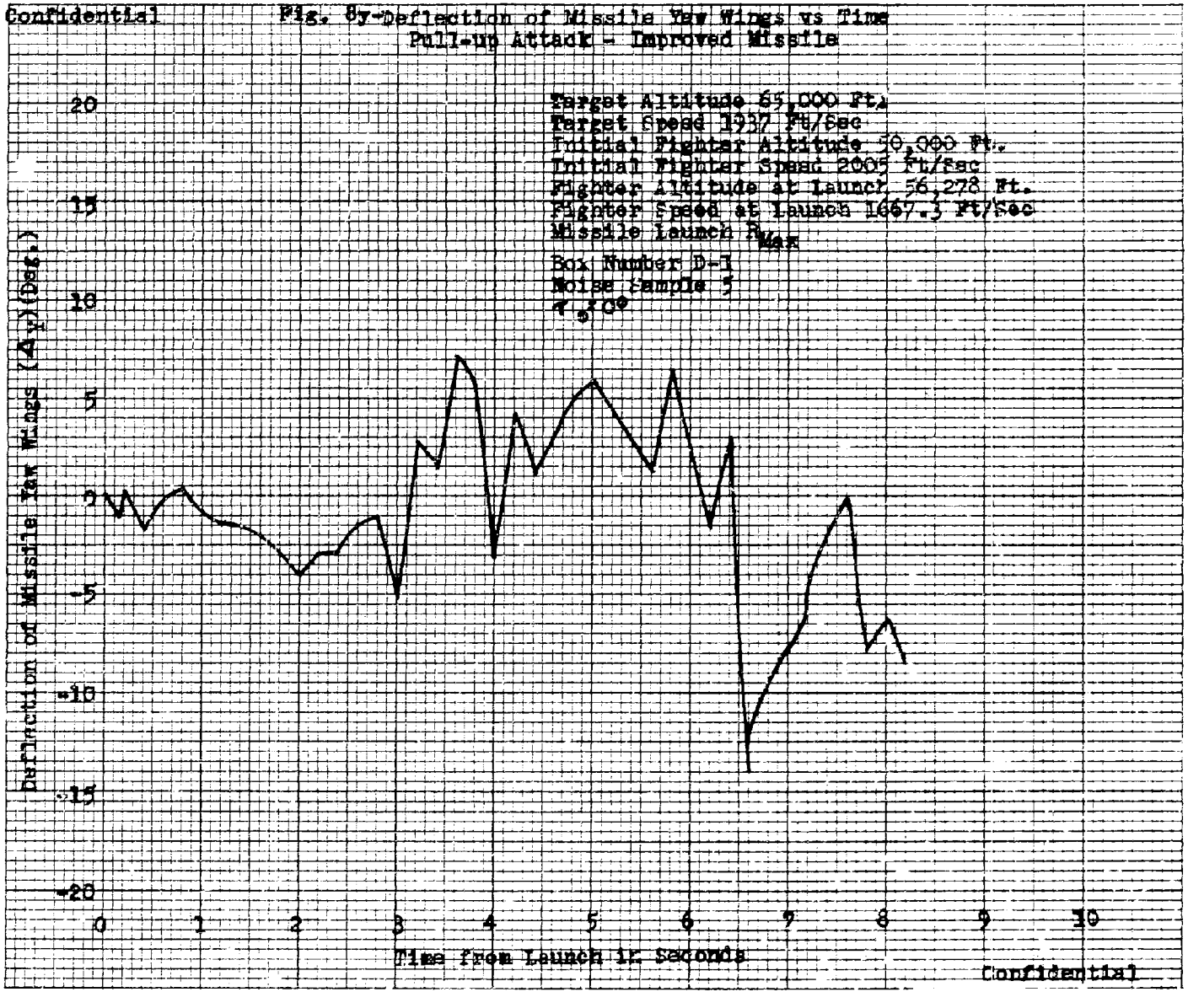


Fig. 8y-Deflection of Missile Yaw Wings vs Time
Pull-up Attack - Improved Missile



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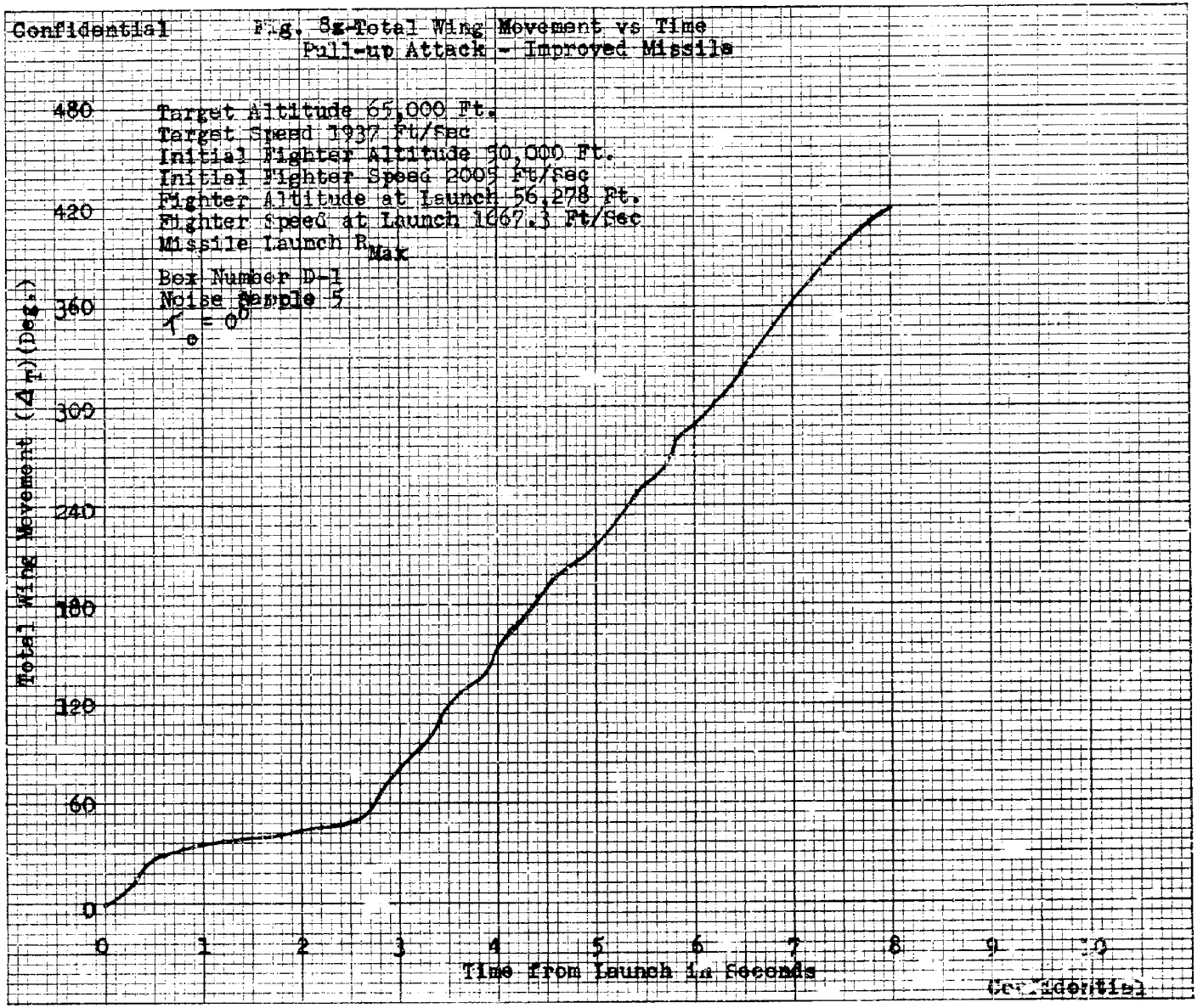
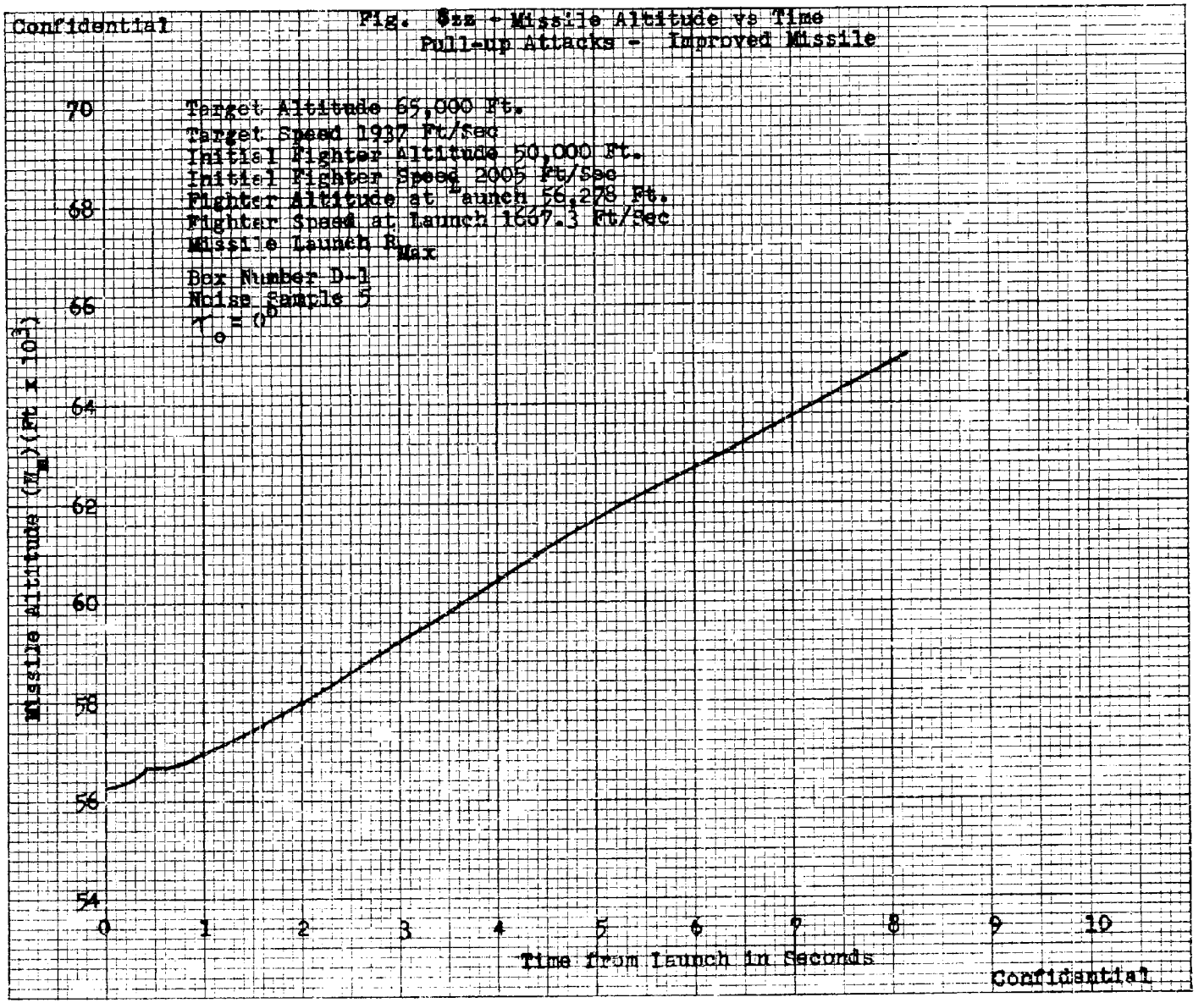


Fig. 322 - Missile Altitude vs Time
Pull-up Attacks - Improved Missile



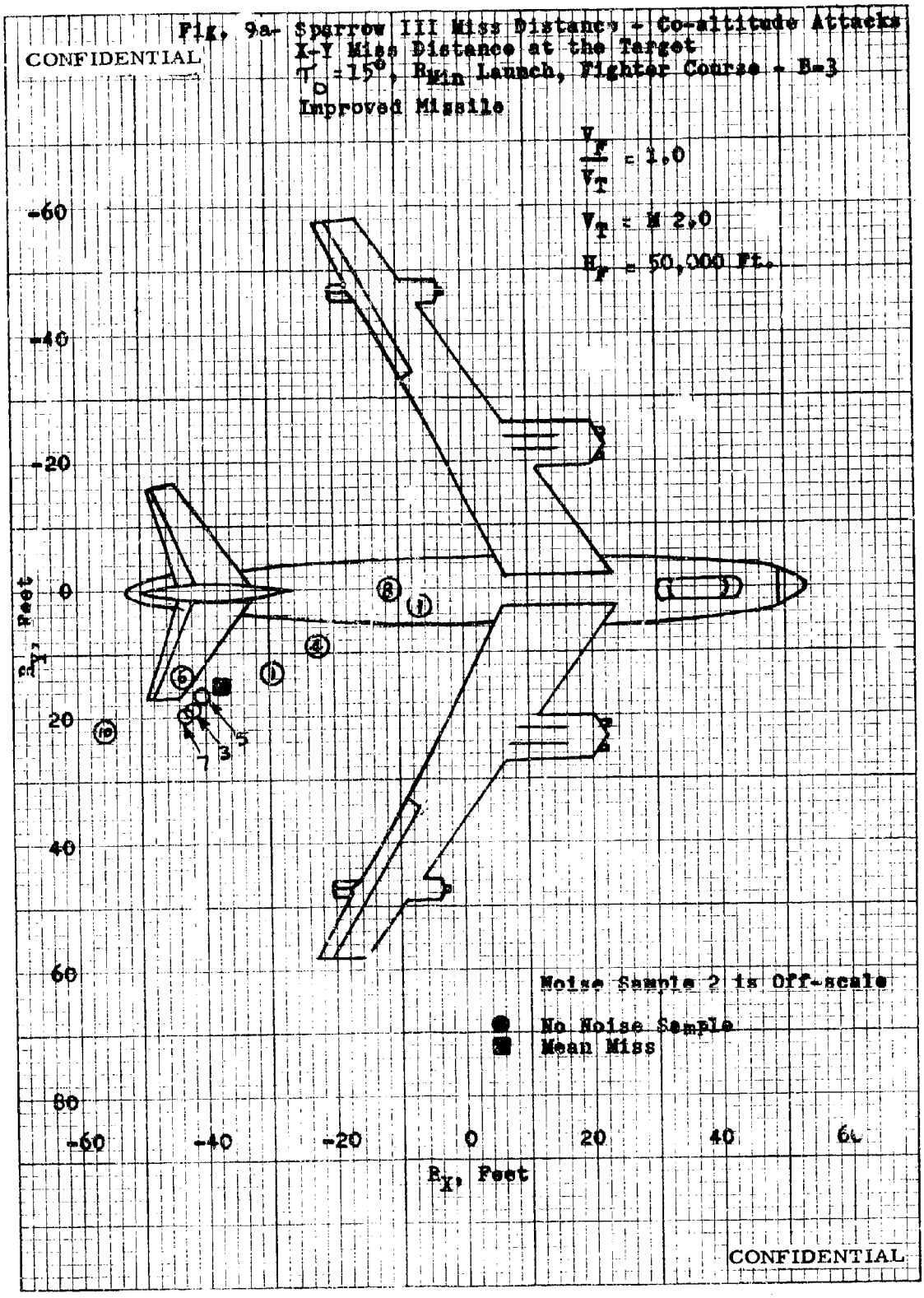


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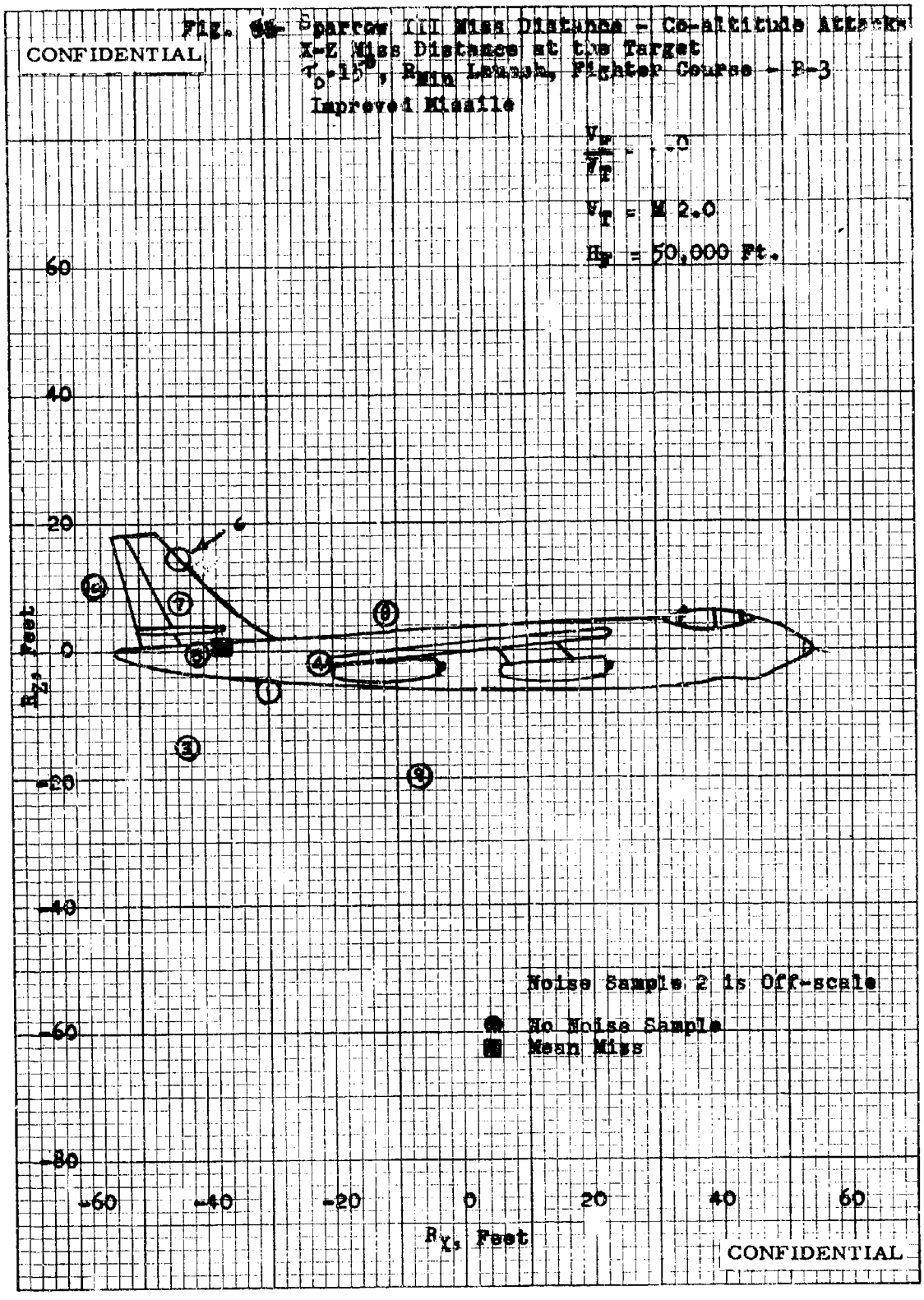
Fig. 66- Sparrow III Miss Distance - Co-altitude Attacks
X-Z Miss Distance at the Target
τ_D=15^0, R_{min} Launch, Fighter Course - P-3
Improved Missile

V_F = 1.0
V_T

V_T = M 2.0

H_F = 50,000 Ft.



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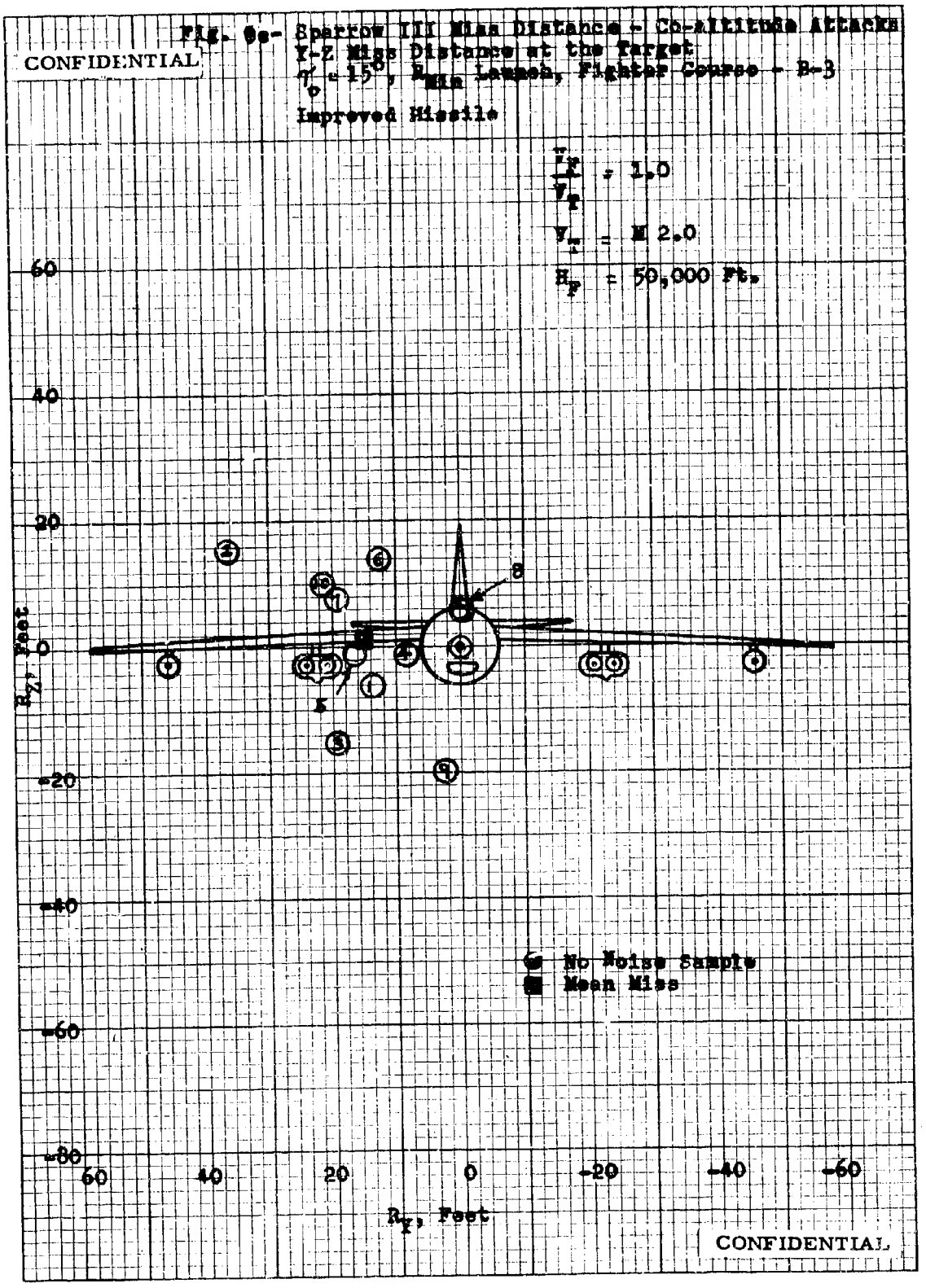

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Fig. 5d -Fighter to Missile Range vs Time
Pull-up Attacks - Improved Missile

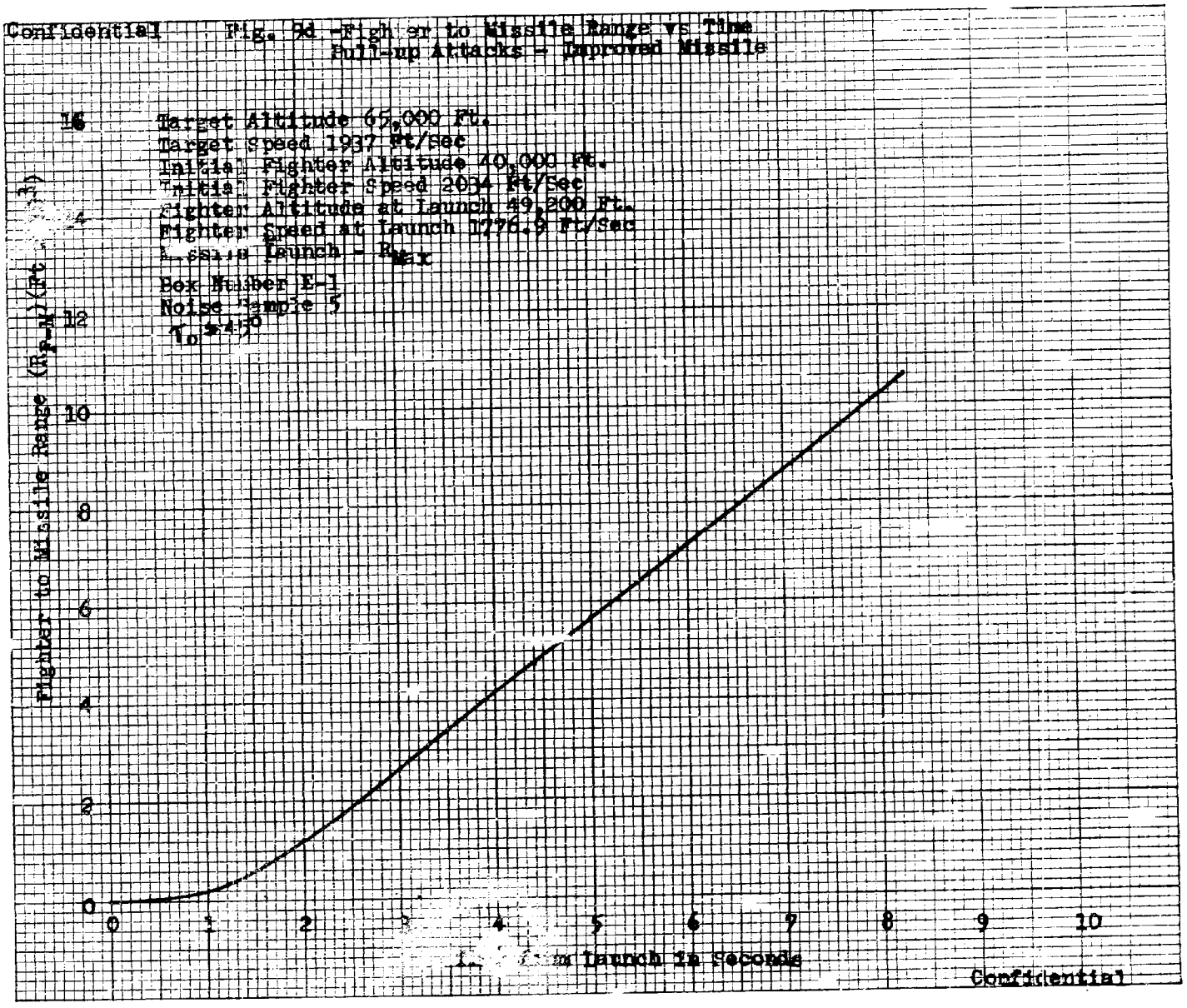

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Fig. 9e - Missile to Target Range vs Time
Pull-up Attacks - Improved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 40,000 Ft.
Initial Fighter Speed 2034 Ft/Sec
Fighter Altitude at Launch 49,200 Ft.
Fighter Speed at Launch 1776.9 Ft/Sec
Missile Launch - R_{Max}

Box Number E-1
Noise Sample 5
$\psi_0 = 45^0$

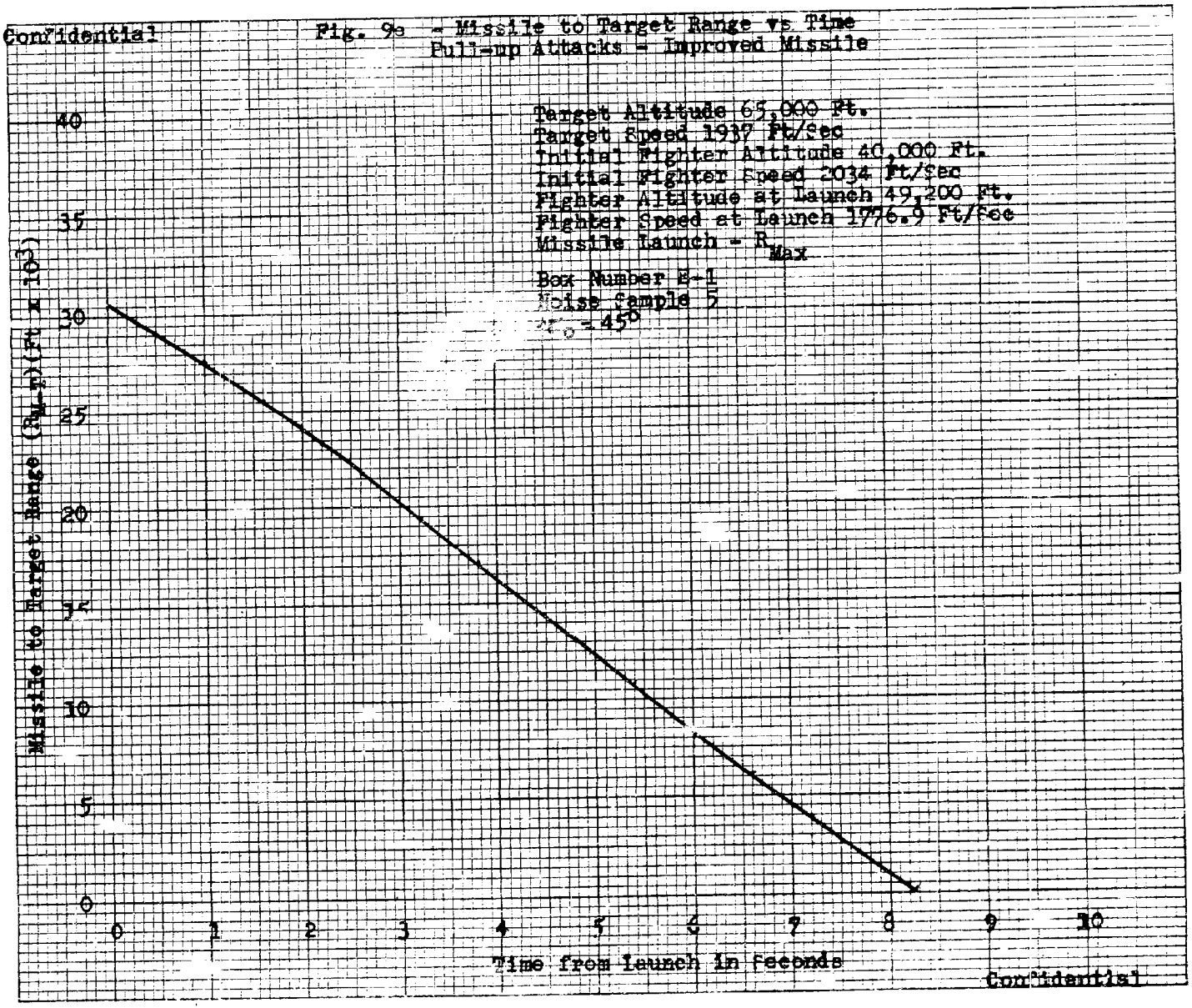

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Fig. 9f - Fighter to Target Range vs Time
Pull-up Attacks - Improved Missile

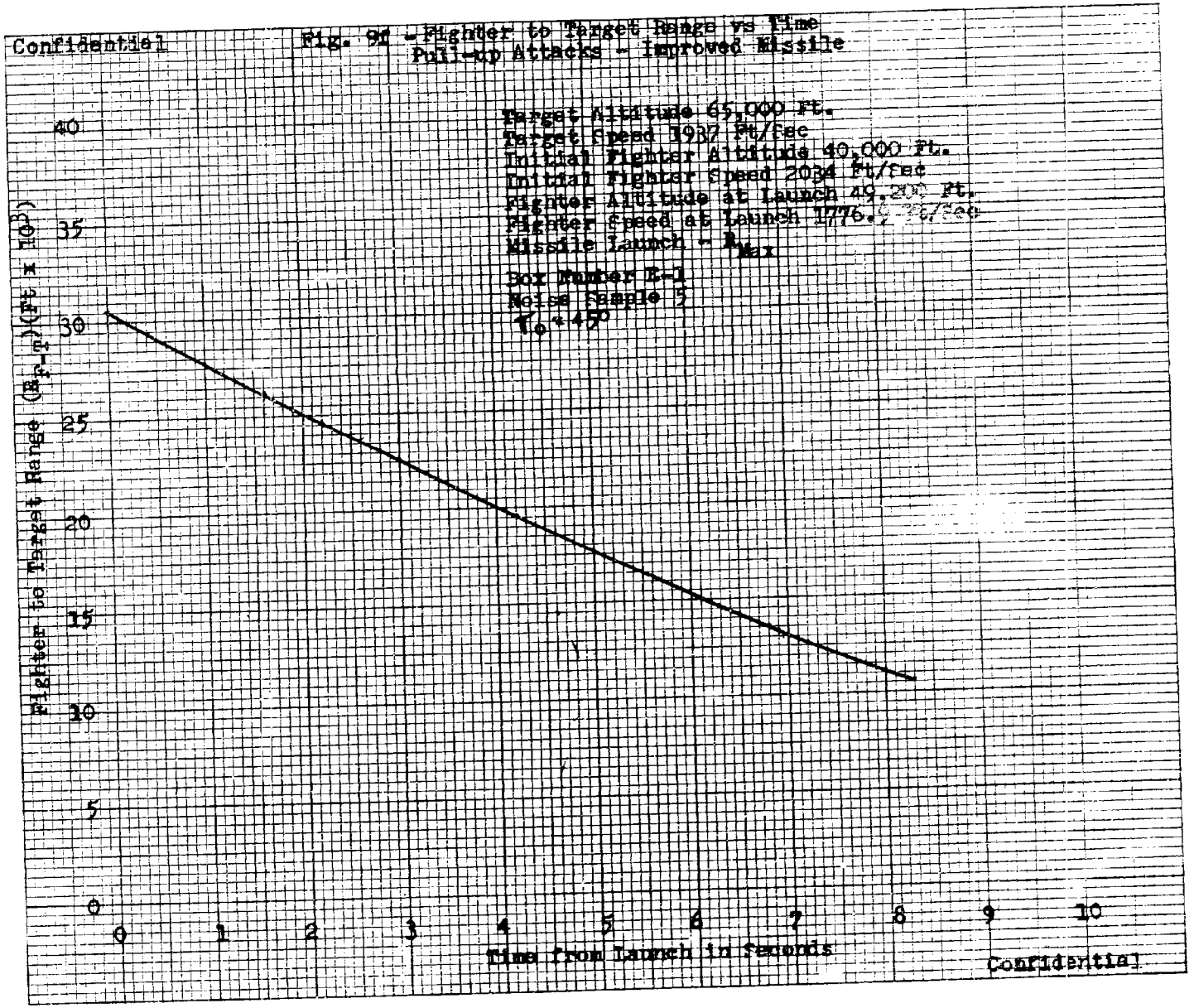

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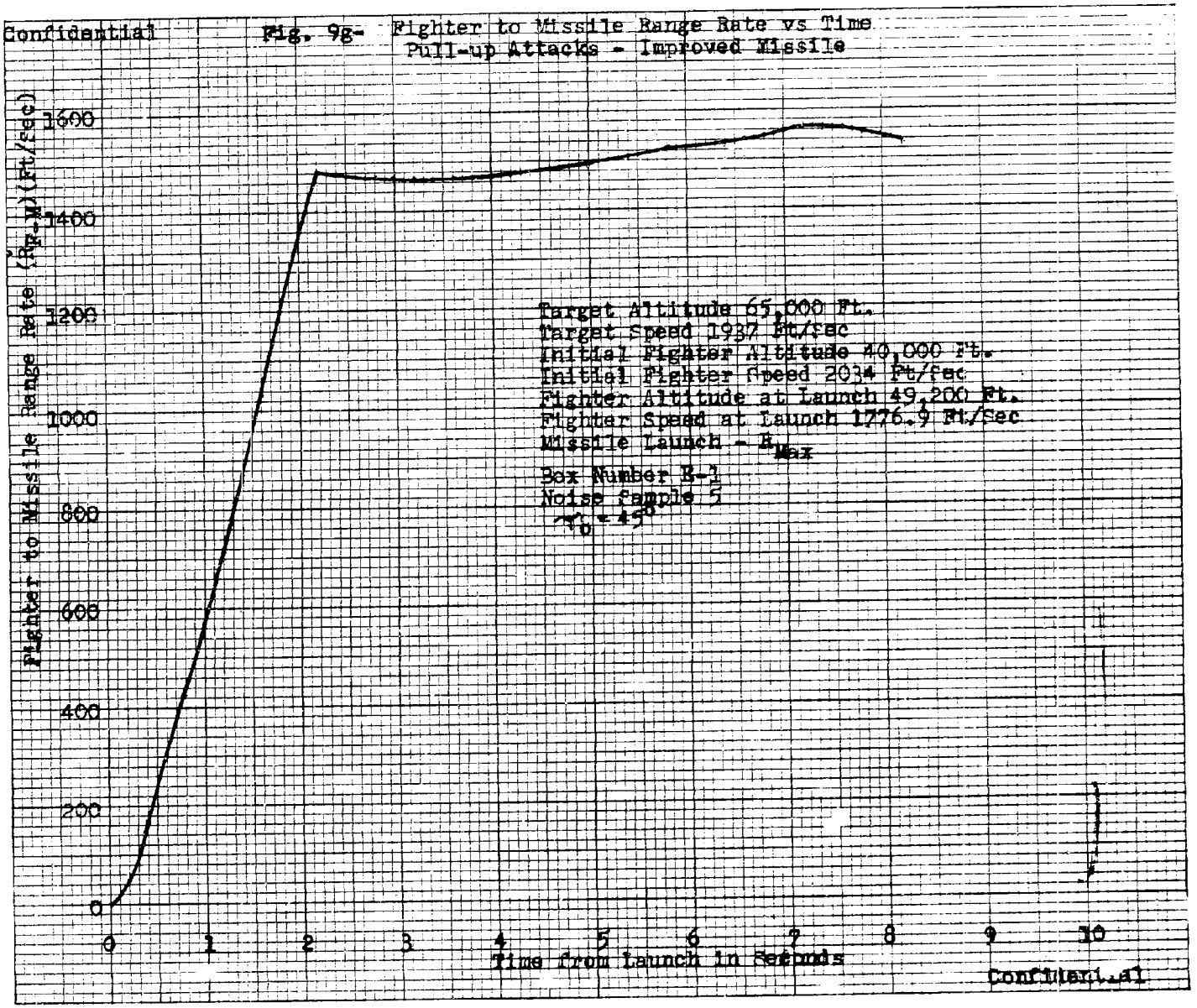
Fig. 9g- Fighter to Missile Range Rate vs Time
Pull-up Attacks - Improved Missile



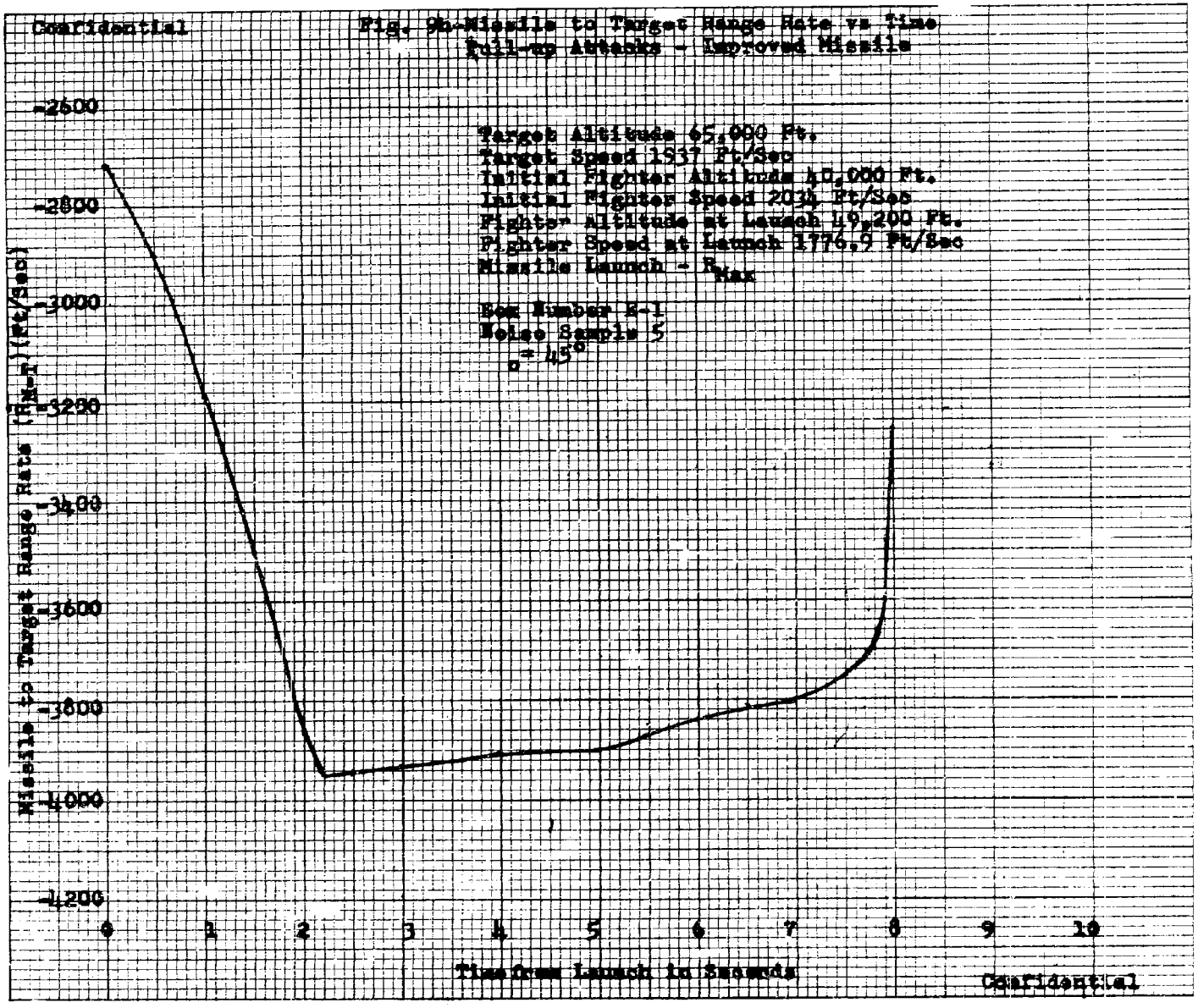

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Fig. 9a-Missile to Target Range Rate vs Time
Roll-up Attacks - Improved Missile
Target Altitude 65,000 Ft.
Target Speed 1837 Ft/Sec
Initial Fighter Altitude 40,000 Ft.
Initial Fighter Speed 2034 Ft/Sec
Fighter Altitude at Launch 49,200 Ft.
Fighter Speed at Launch 1776.9 Ft/Sec
Missile Launch - R_{Max}
Run Number R-1
Noise Sample 5
$\sigma = 45^{\circ}$
Missile to Target Range Rate (N.F.) (Ft/Sec)
-2600
-2800
-3000
-3200
-3400
-3600
-3800
-4000
-4200
0
1
2
3
4
5
6
7
8
9
10
Time from Launch in Seconds
Confidential

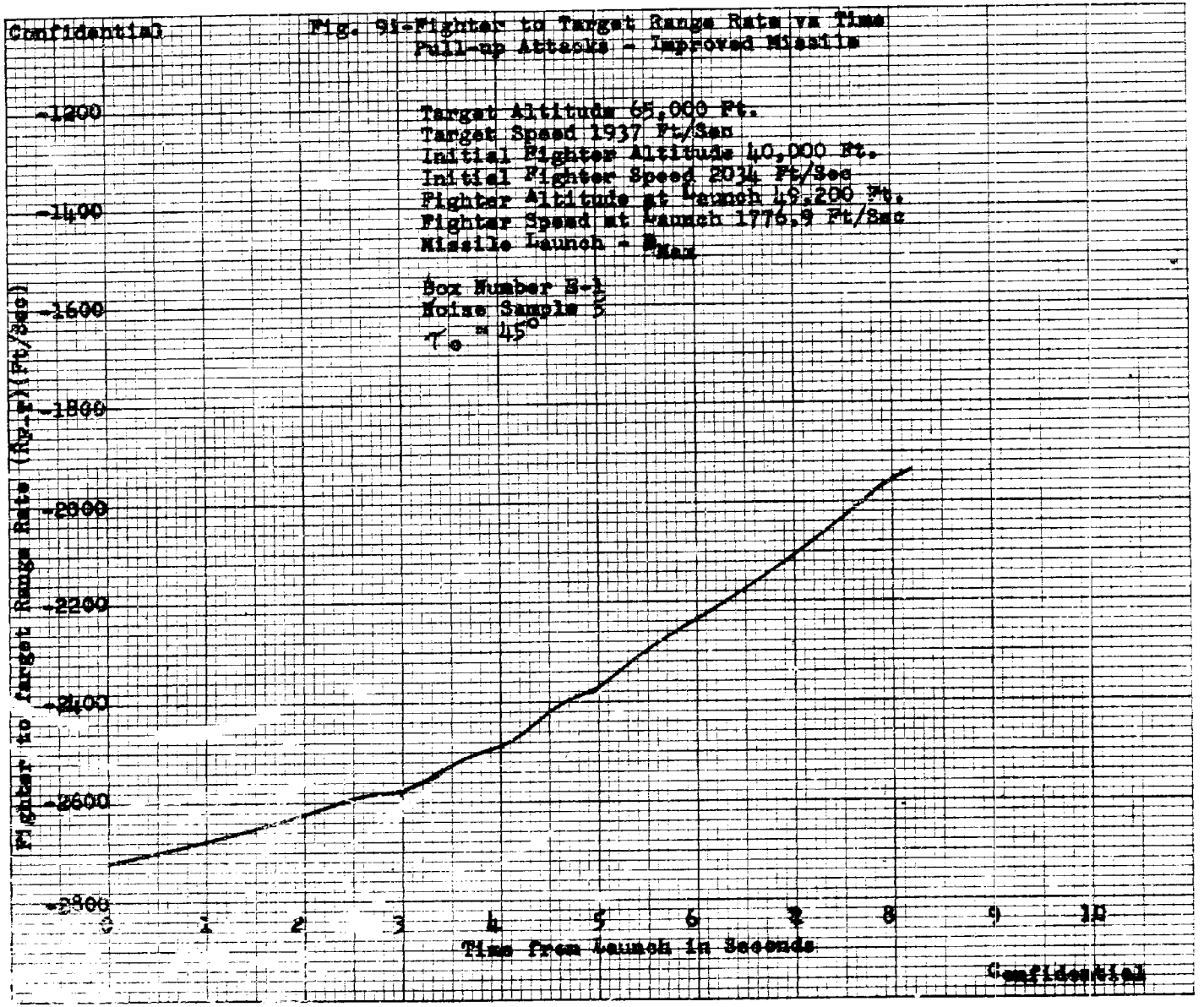

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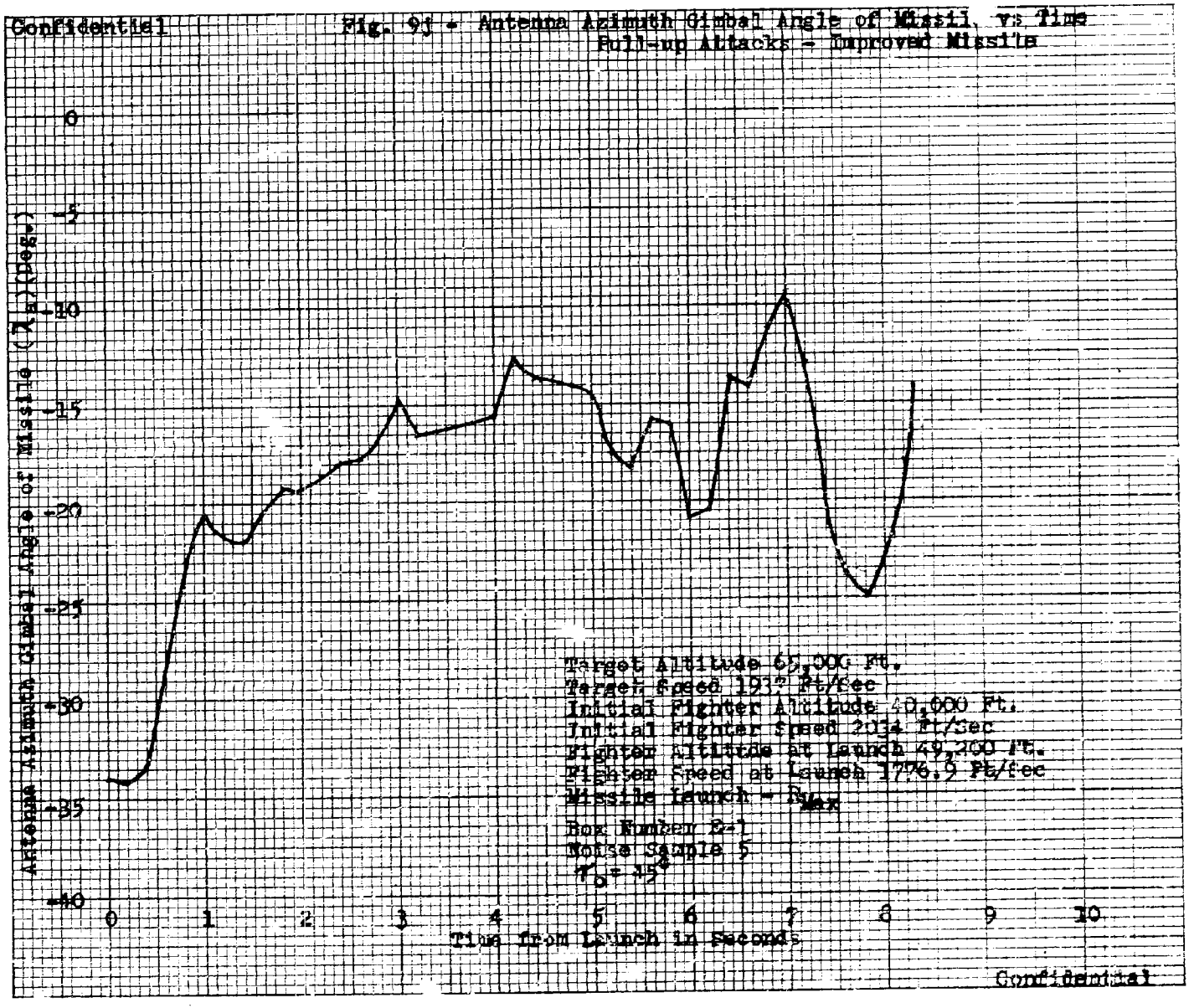
Fig. 9j - Antenna Azimuth Gimbal Angle of Missil vs Time
Full-up Attacks - Improved Missile



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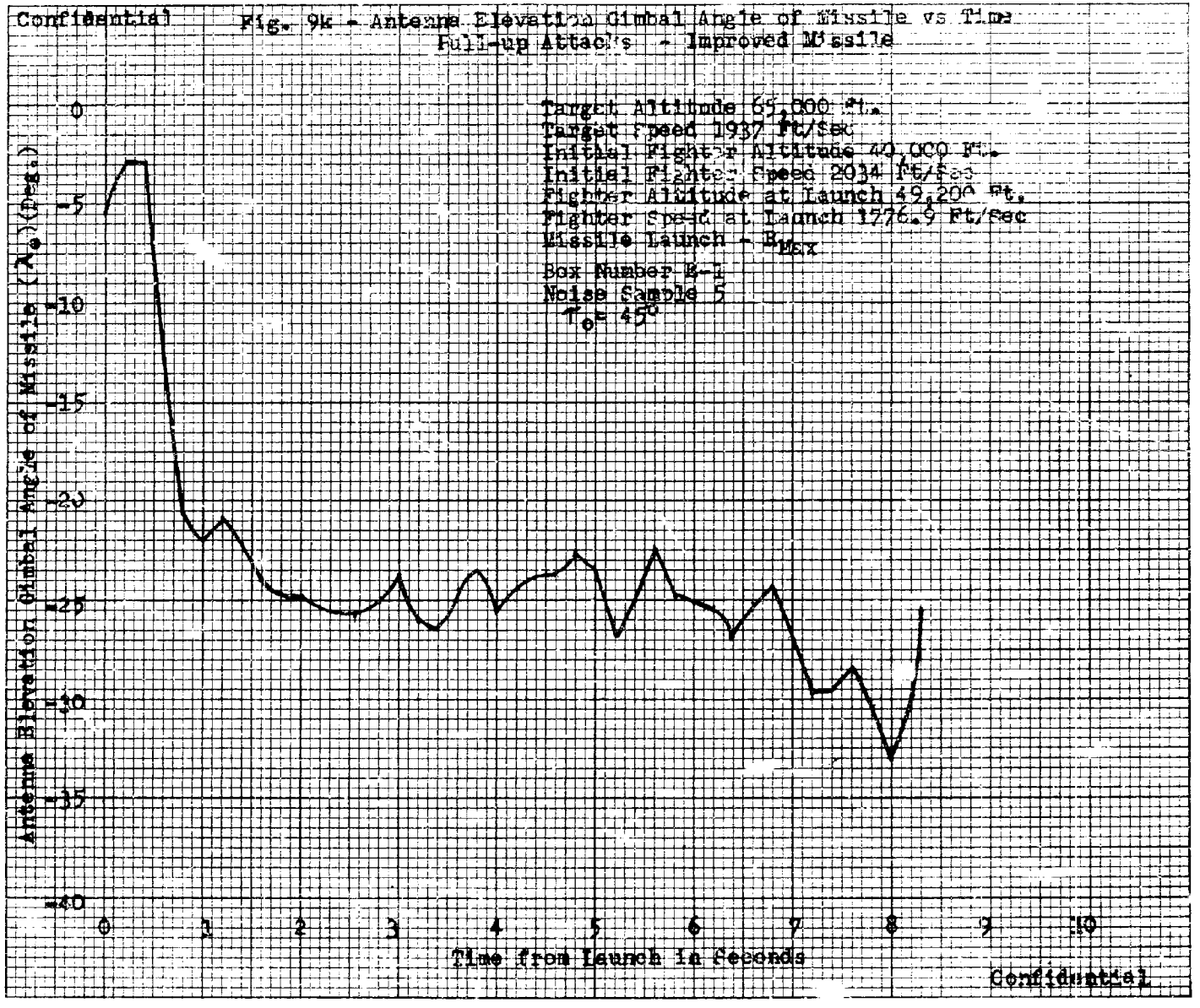

Fig. 9-1 - Missile Lead Angle vs Time
Pull-up Attacks - Improved Missile

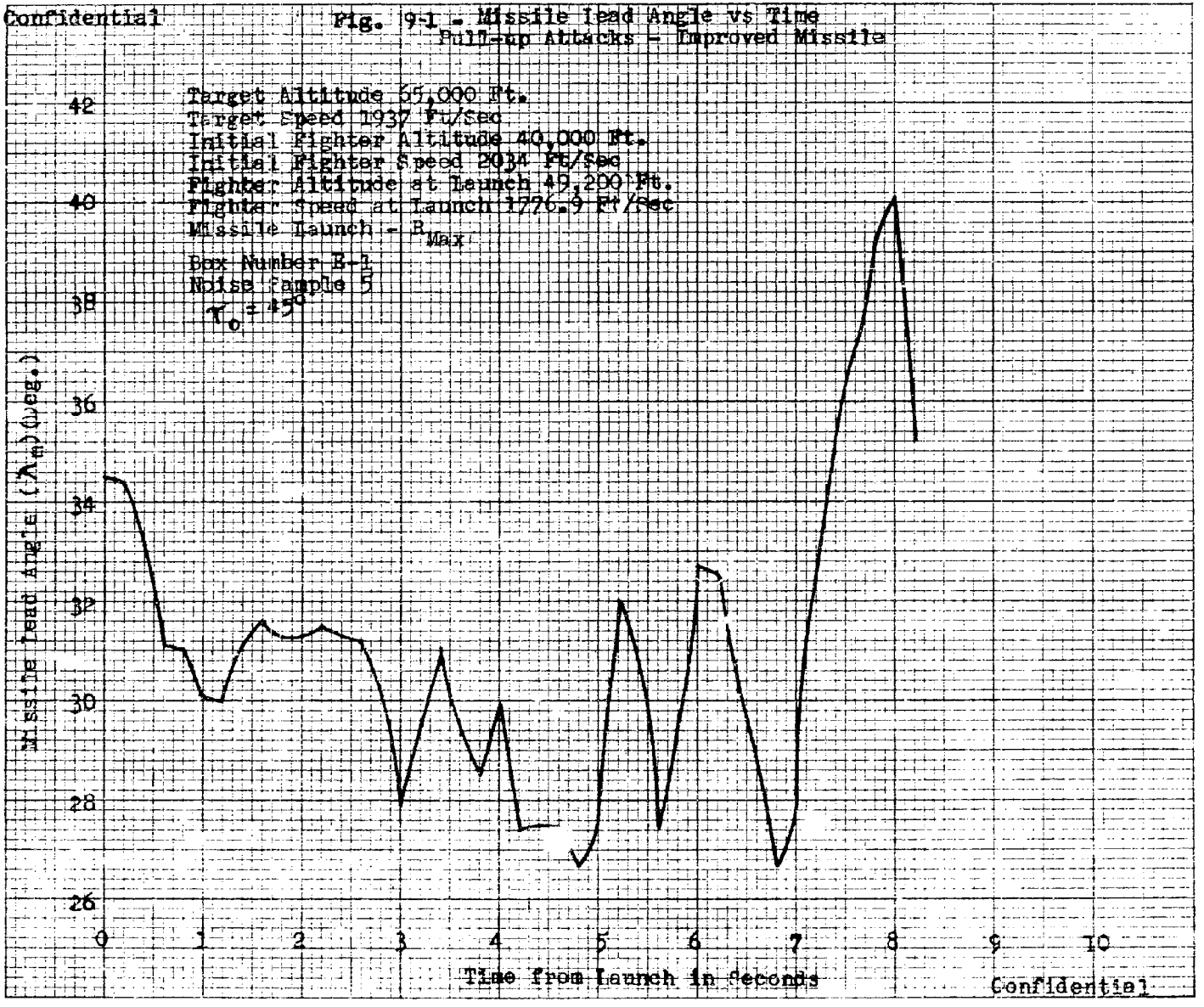

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Fig. 9a - Azimuth Line of Flight Rate of Missile Vs Time
Pull-up Attacks - Improved Missile

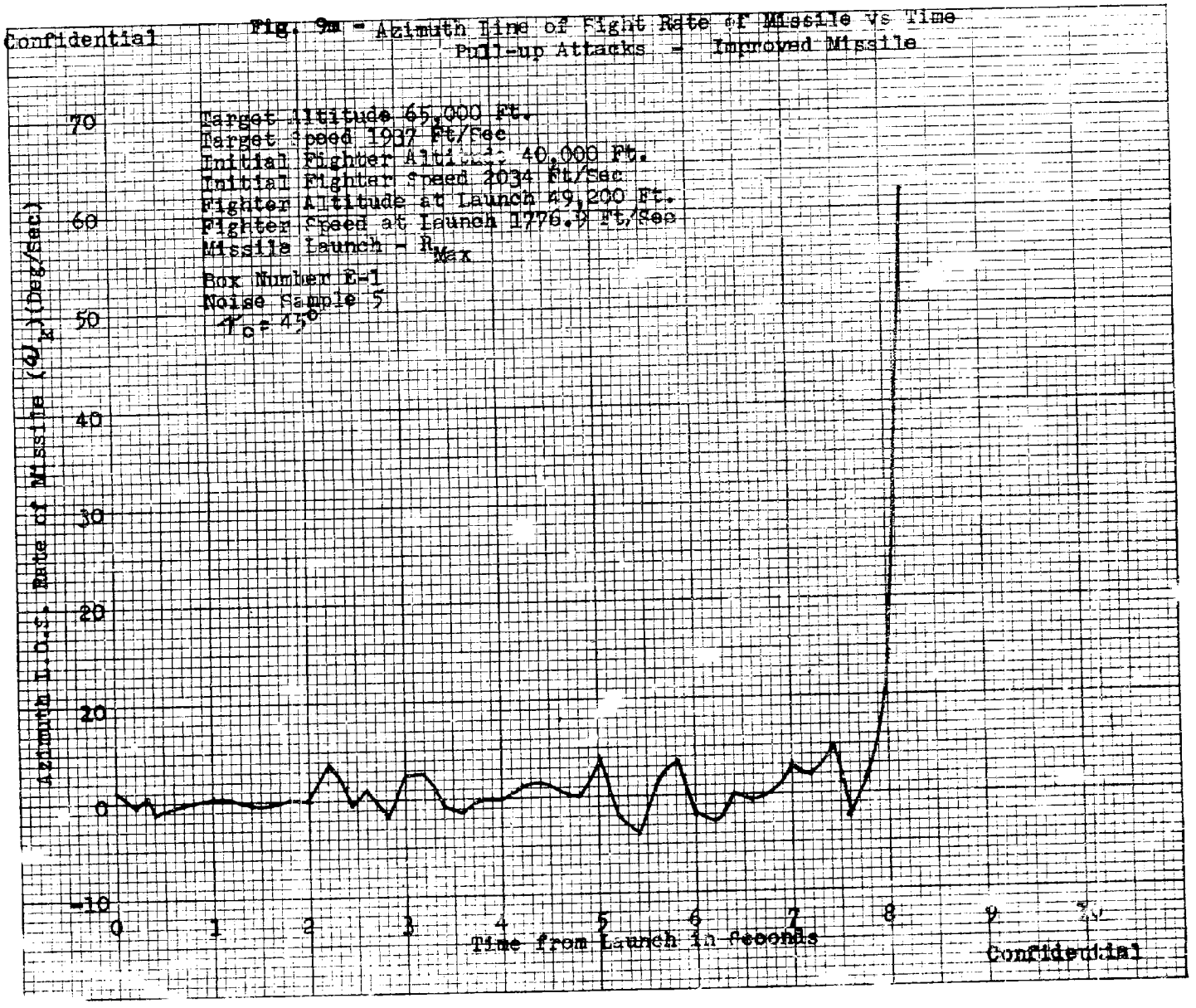

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Fig. 9n - Elevation Line of Sight Rate of Missile vs Time
Pull-up Attacks - Improved Missile

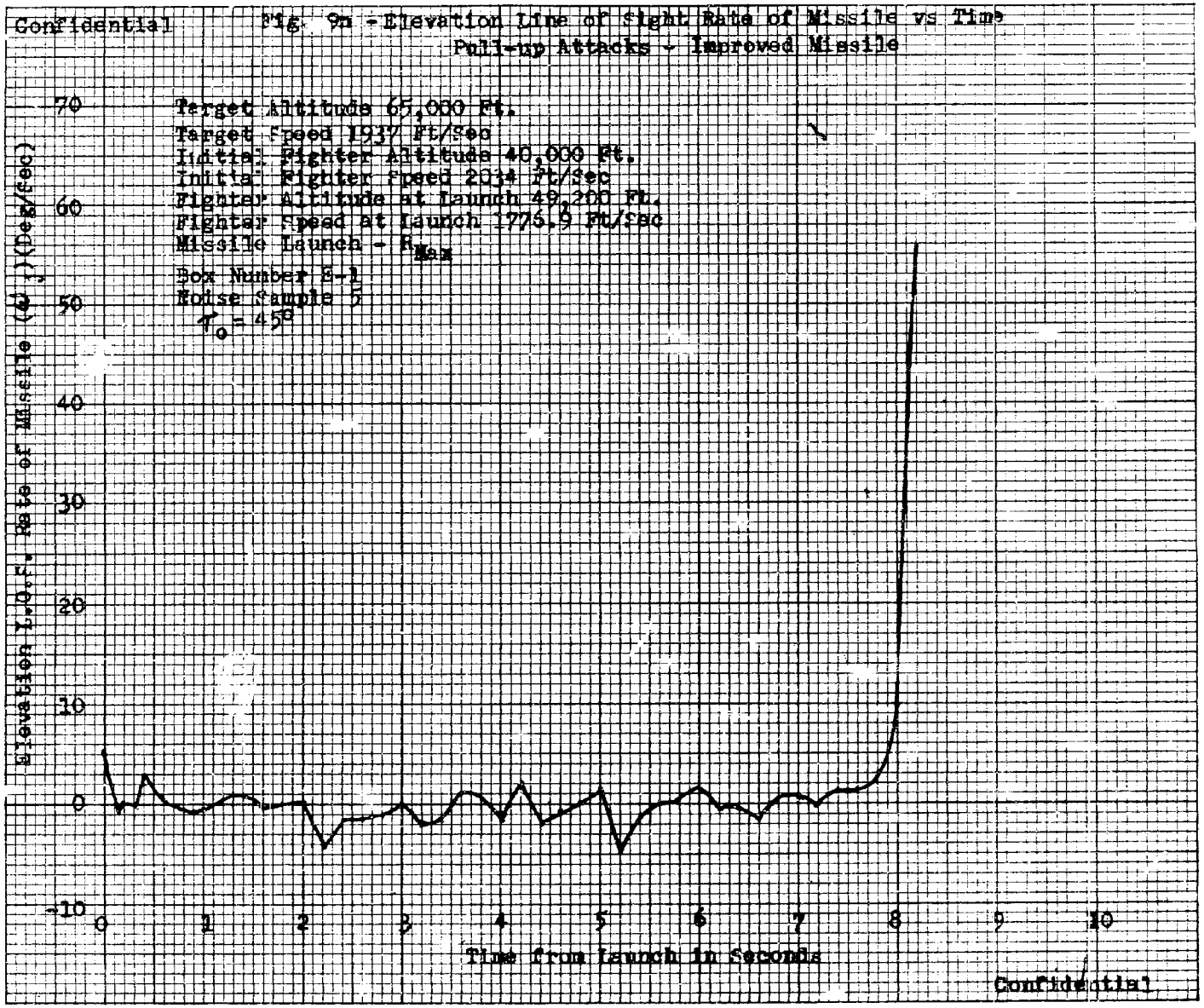

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Fig. 96 -Missile Velocity vs Time
Full-up Attacks - Improved Missile

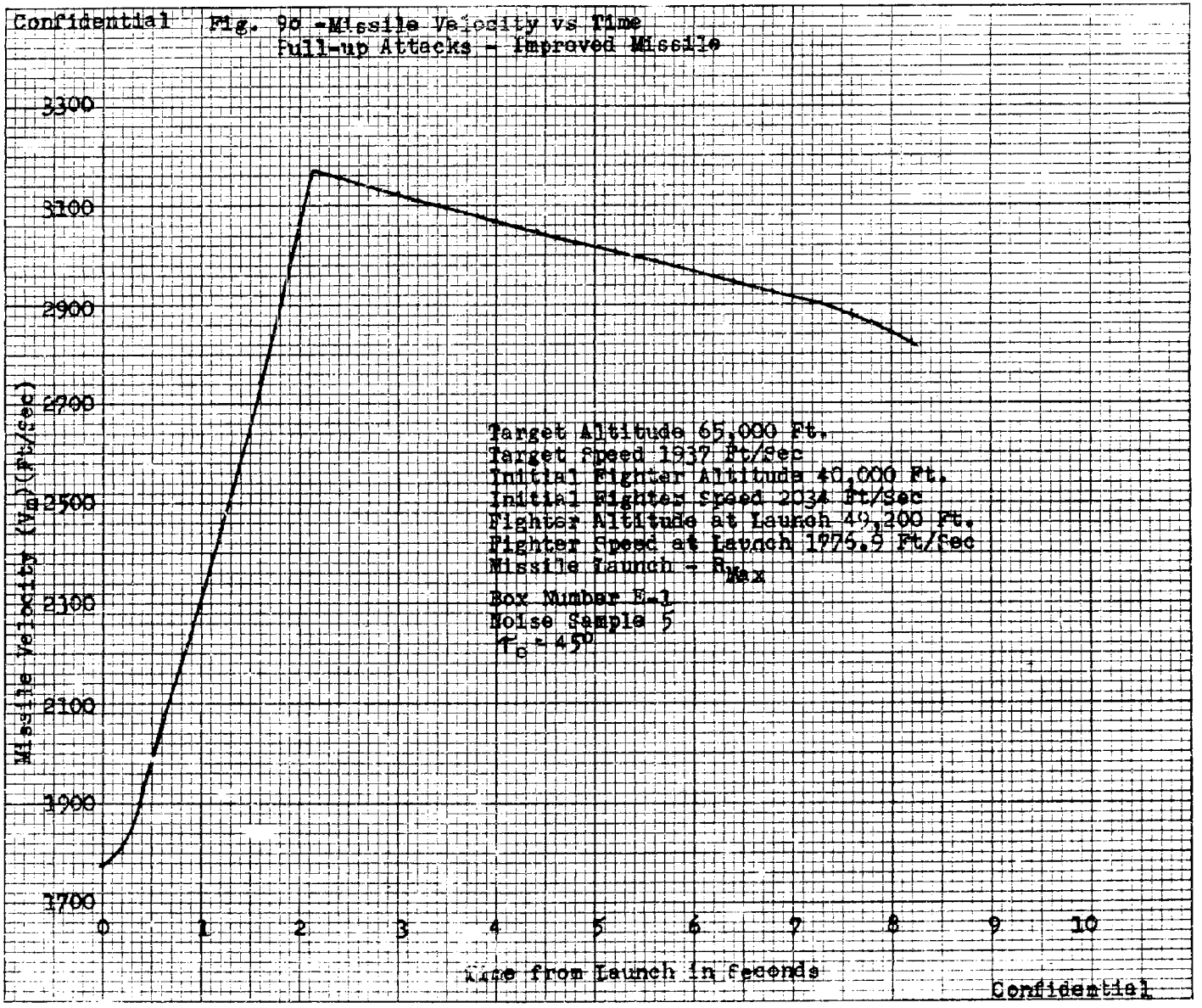

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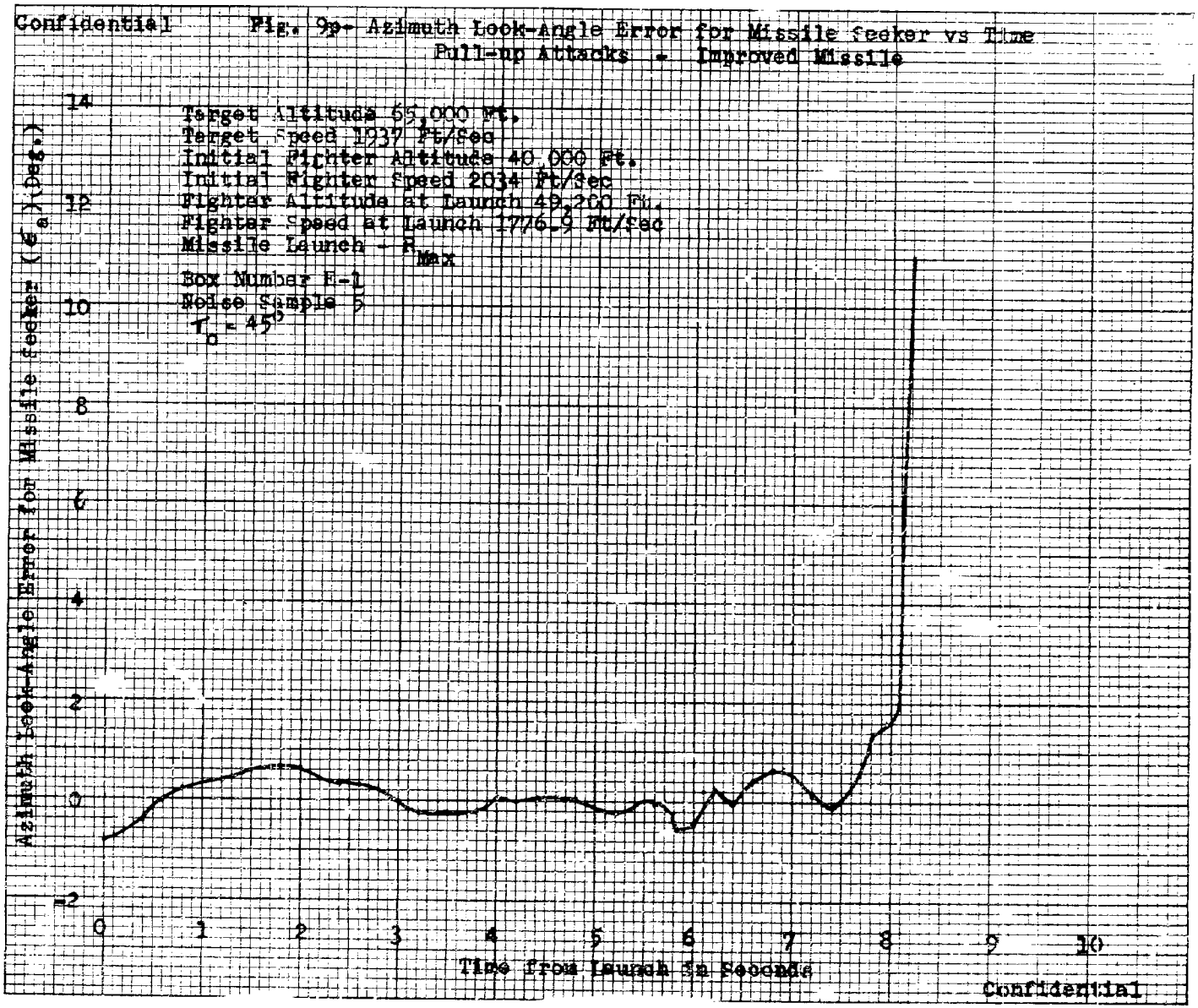
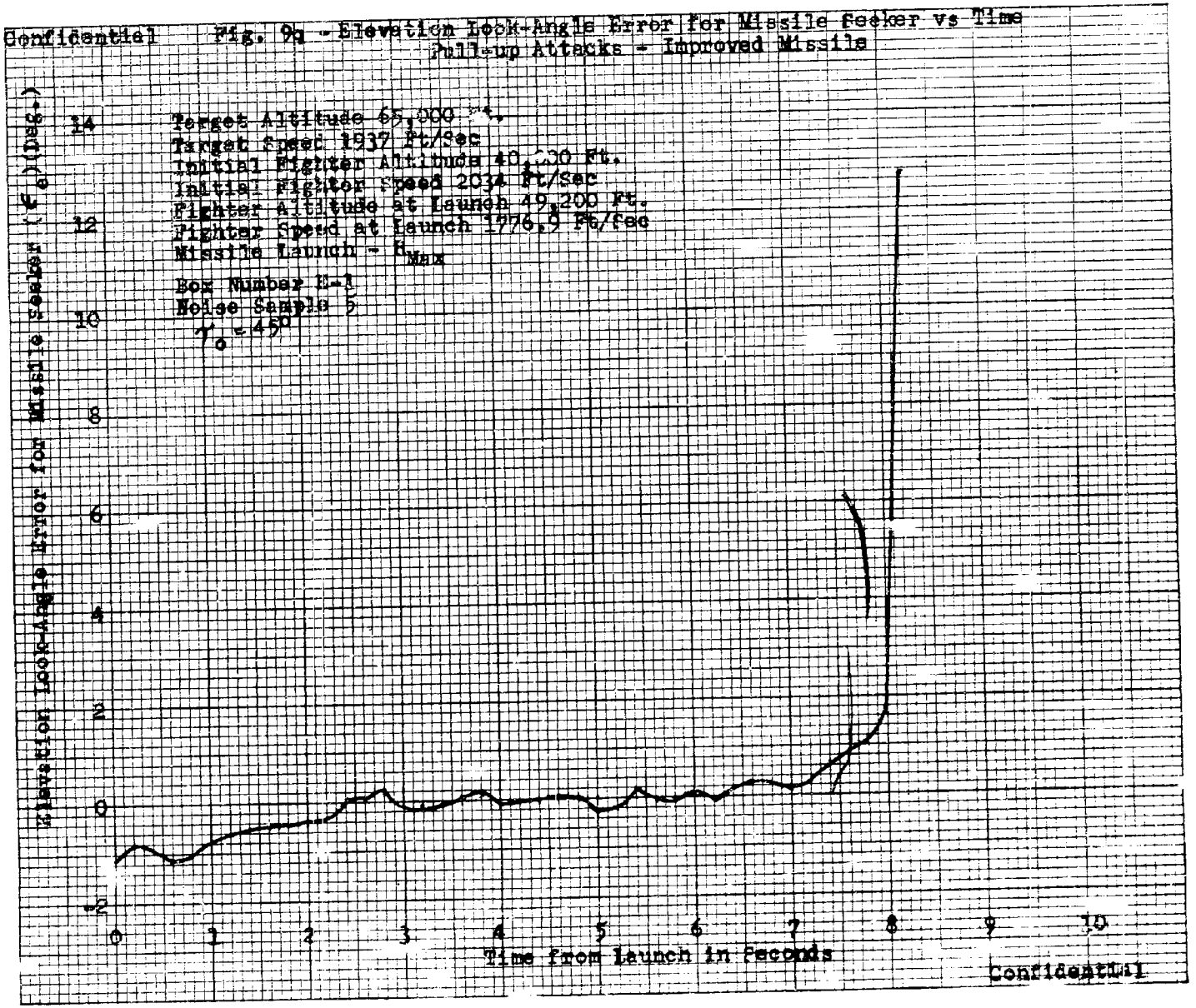
Fig. 9p- Azimuth Look-Angle Error for Missile Seeker vs Time
Pull-up Attacks - Improved Missile





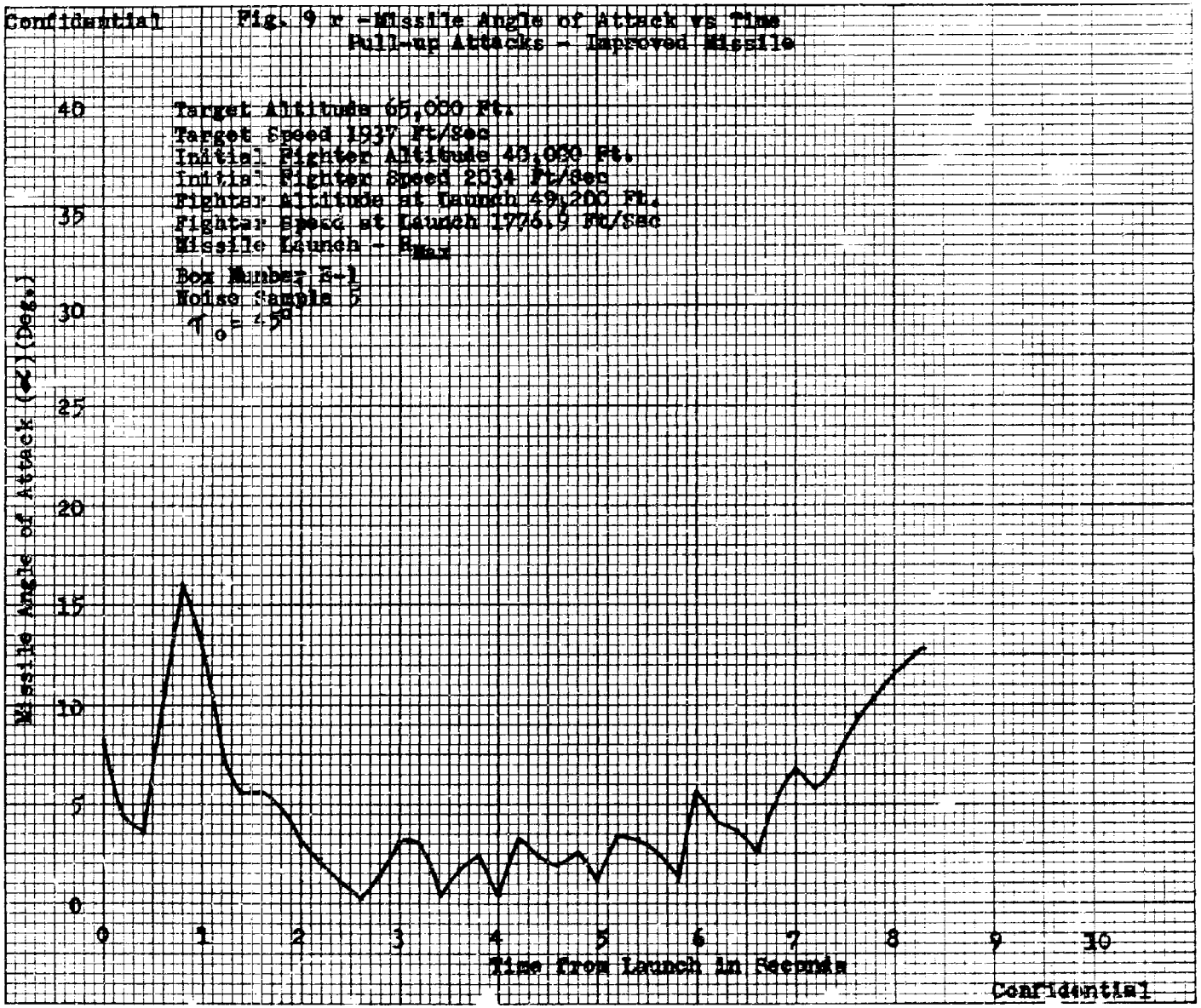

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Fig. 9 x -Missile Angle of Attack vs Time
Pull-up Attacks - Improved Missile
Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 40,000 Ft.
Initial Fighter Speed 2034 Ft/Sec
Fighter altitude at Launch 49,200 Ft.
Fighter Speed at Launch 1776.9 Ft/Sec
Missile Launch - R max
Box Number 8-1
Noise Sample 5
σ = 4.5°
Missile Angle of Attack (α) (Deg.)
Time from Launch in Seconds
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Fig. 9a - Missile and Fighter Roll Angles vs Time
Pull-up Attacks - Improved Missile

Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Speed 2034 Ft/Sec
Initial Fighter Altitude 40,000 Ft.
Fighter Altitude at Launch 49,200 Ft.
Fighter Speed at Launch 1776.9 Ft/Sec
Missile Launch - R_{max}

P α Number E-1
Noise Sample 5
$\sigma_\phi = 45°$

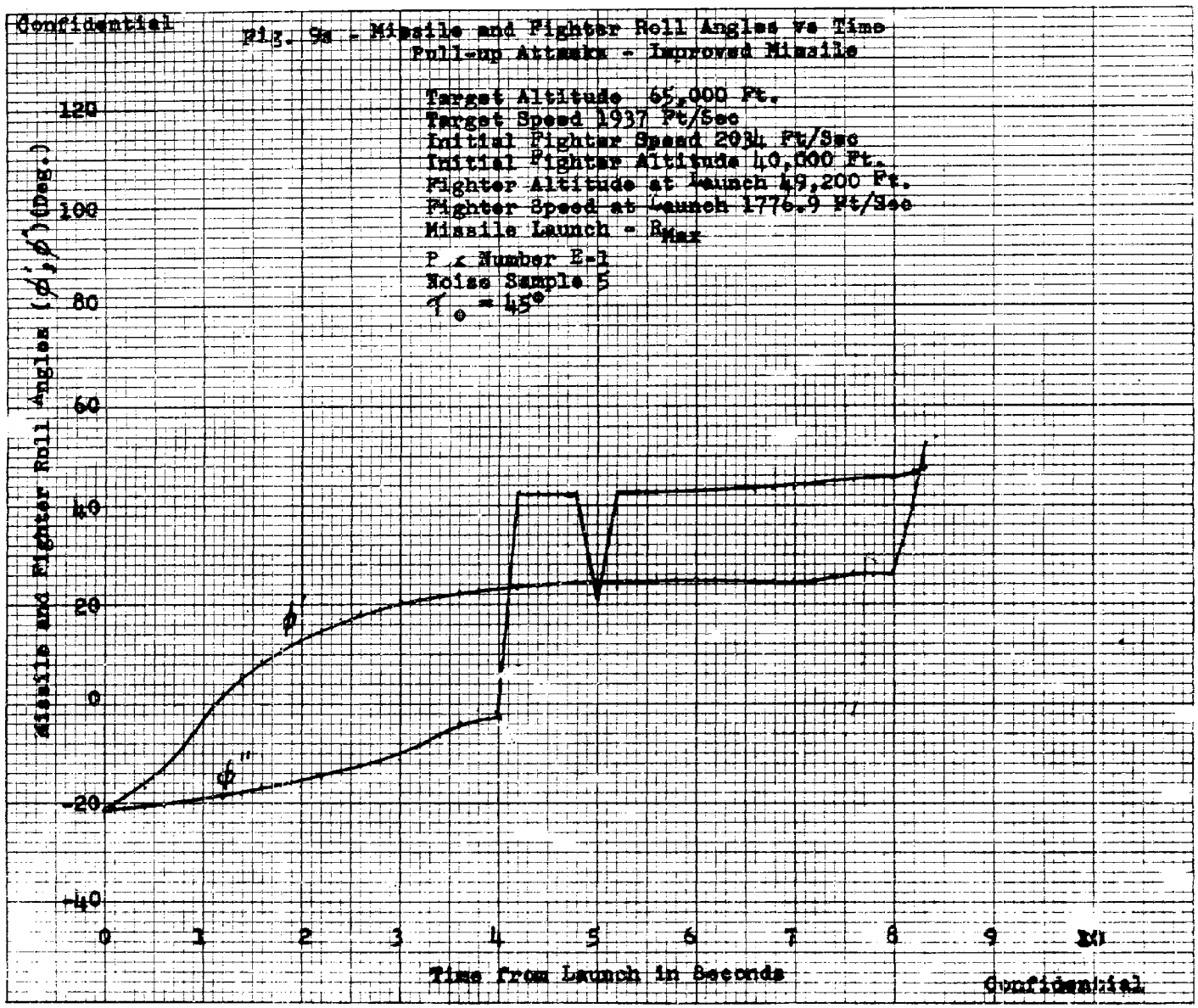

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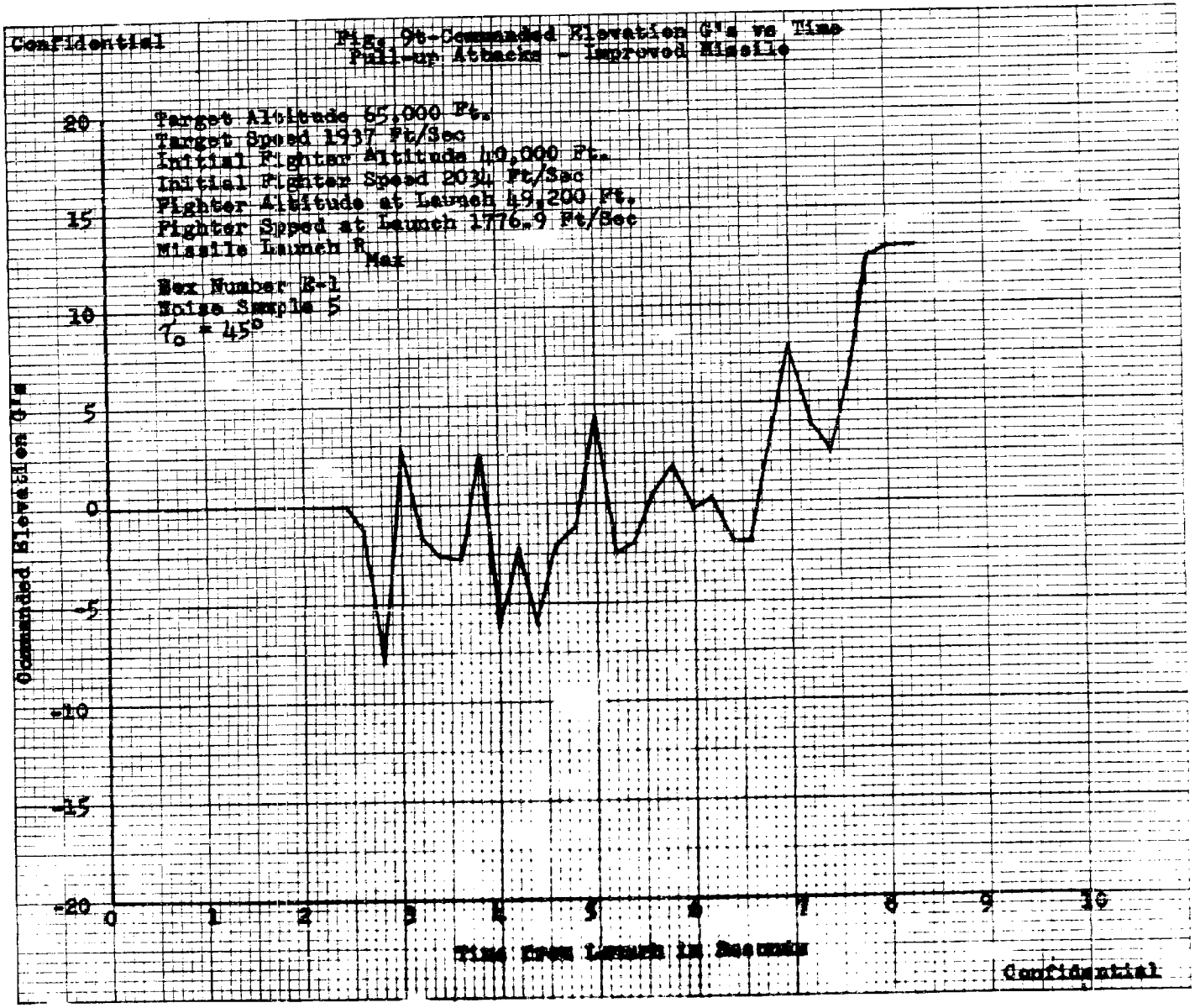
Fig. 9--Commanded Elevation G's vs Time
Pull-up Attacks - Improved Missile



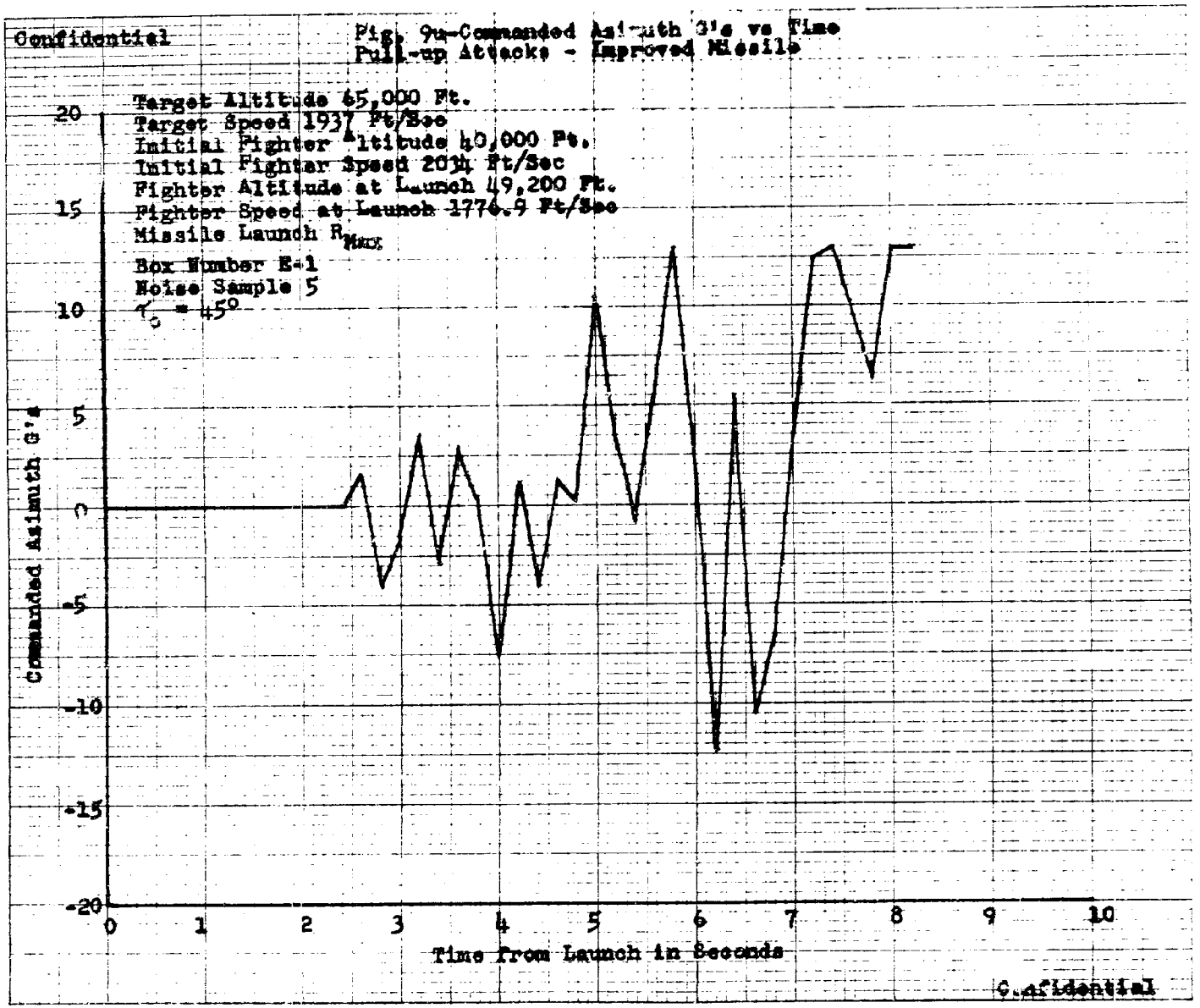

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Fig. 9a-Commanded Azimuth G's vs Time
Pull-up Attacks - Improved Missile
Target Altitude 65,000 Ft.
Target Speed 1937 Ft/Sec
Initial Fighter Altitude 40,000 Ft.
Initial Fighter Speed 2034 Ft/Sec
Fighter Altitude at Launch 49,200 Ft.
Fighter Speed at Launch 1776.9 Ft/Sec
Missile Launch R_{MAX}
Box Number E-1
Noise Sample 5
$\tau_o = 45^o$
Commanded Azimuth G's
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8
9
10
Time from Launch in Seconds
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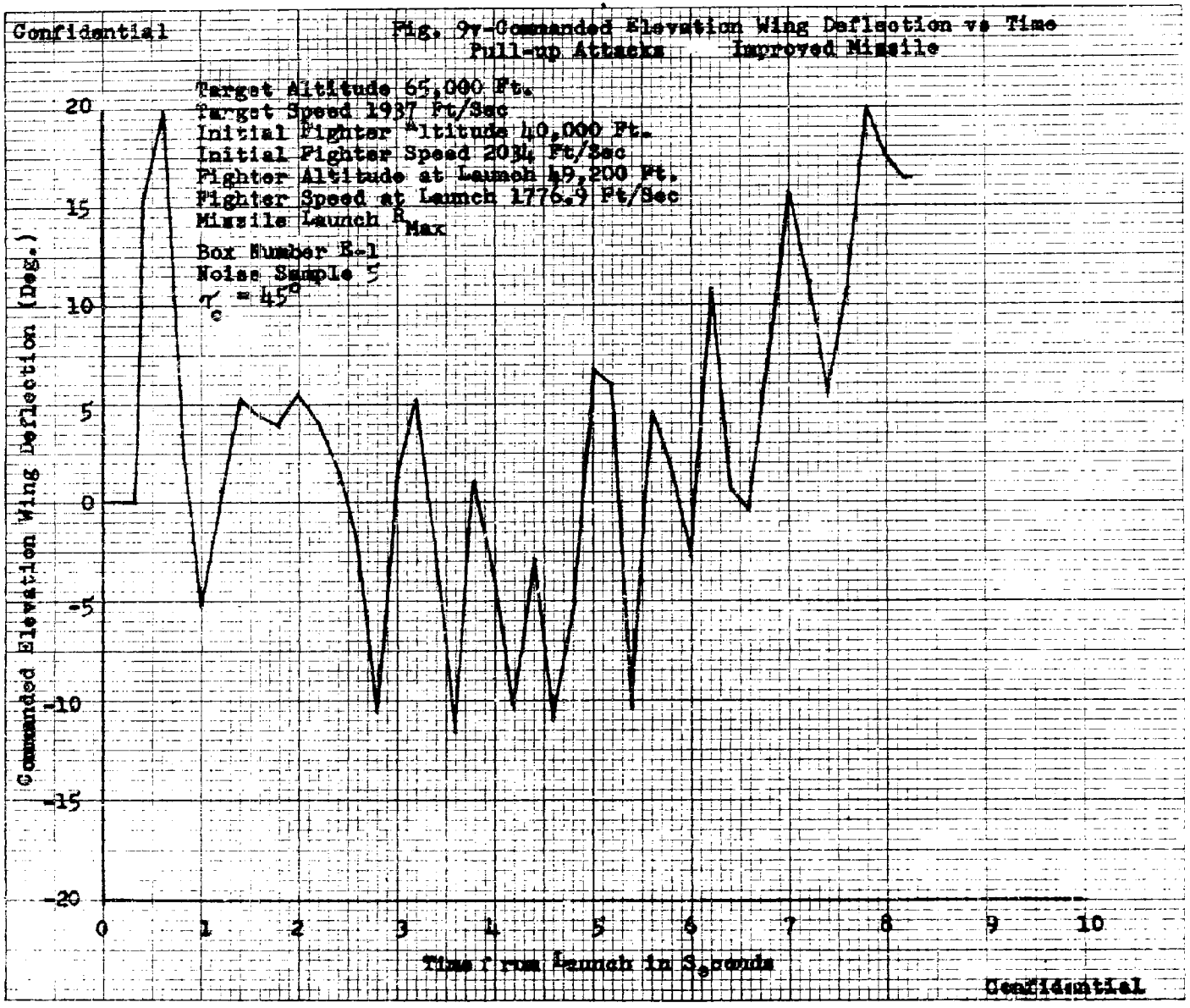
Fig. 9y-Commanded Elevation Wing Deflection vs Time
Pull-up Attacks Improved Missile



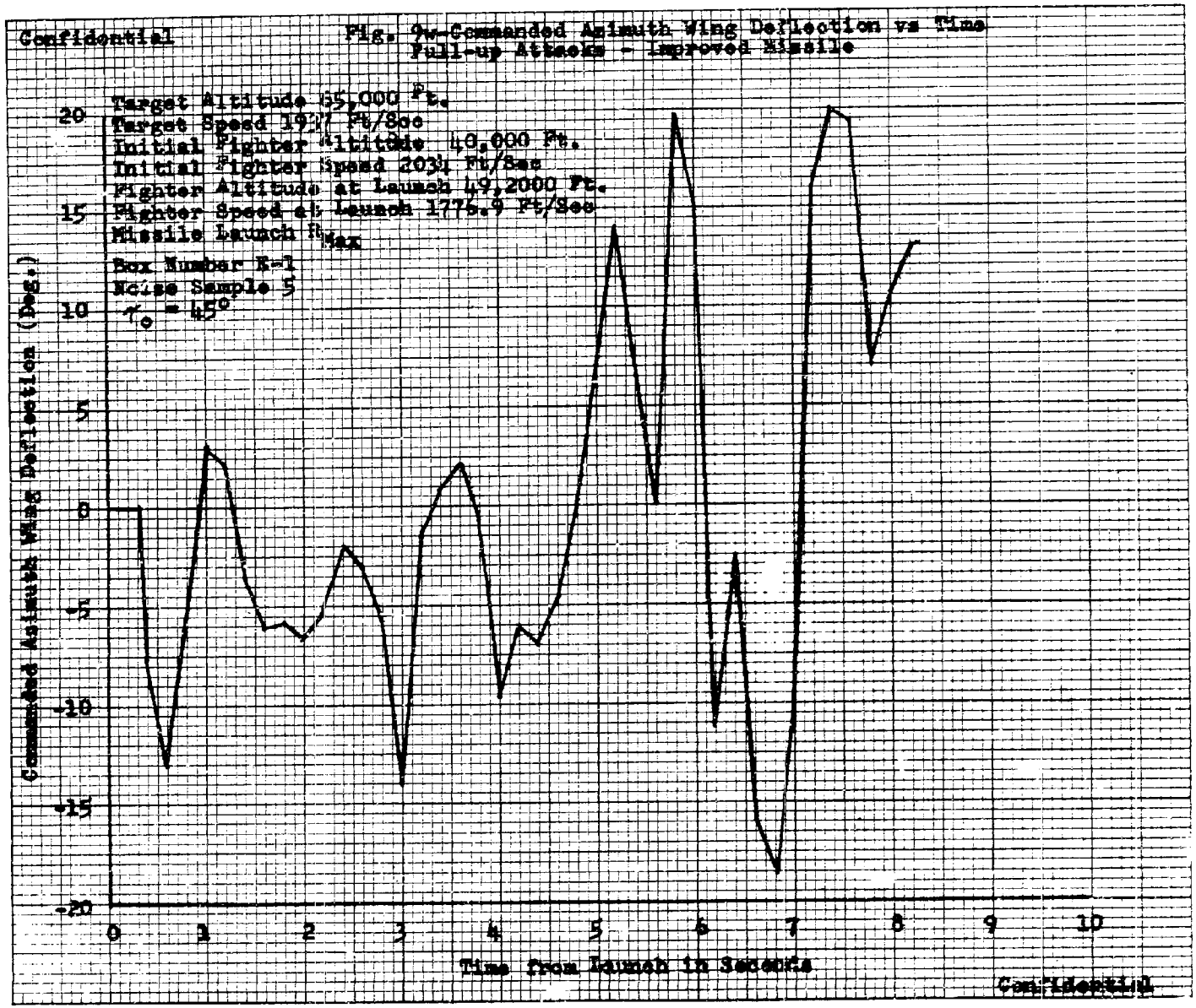


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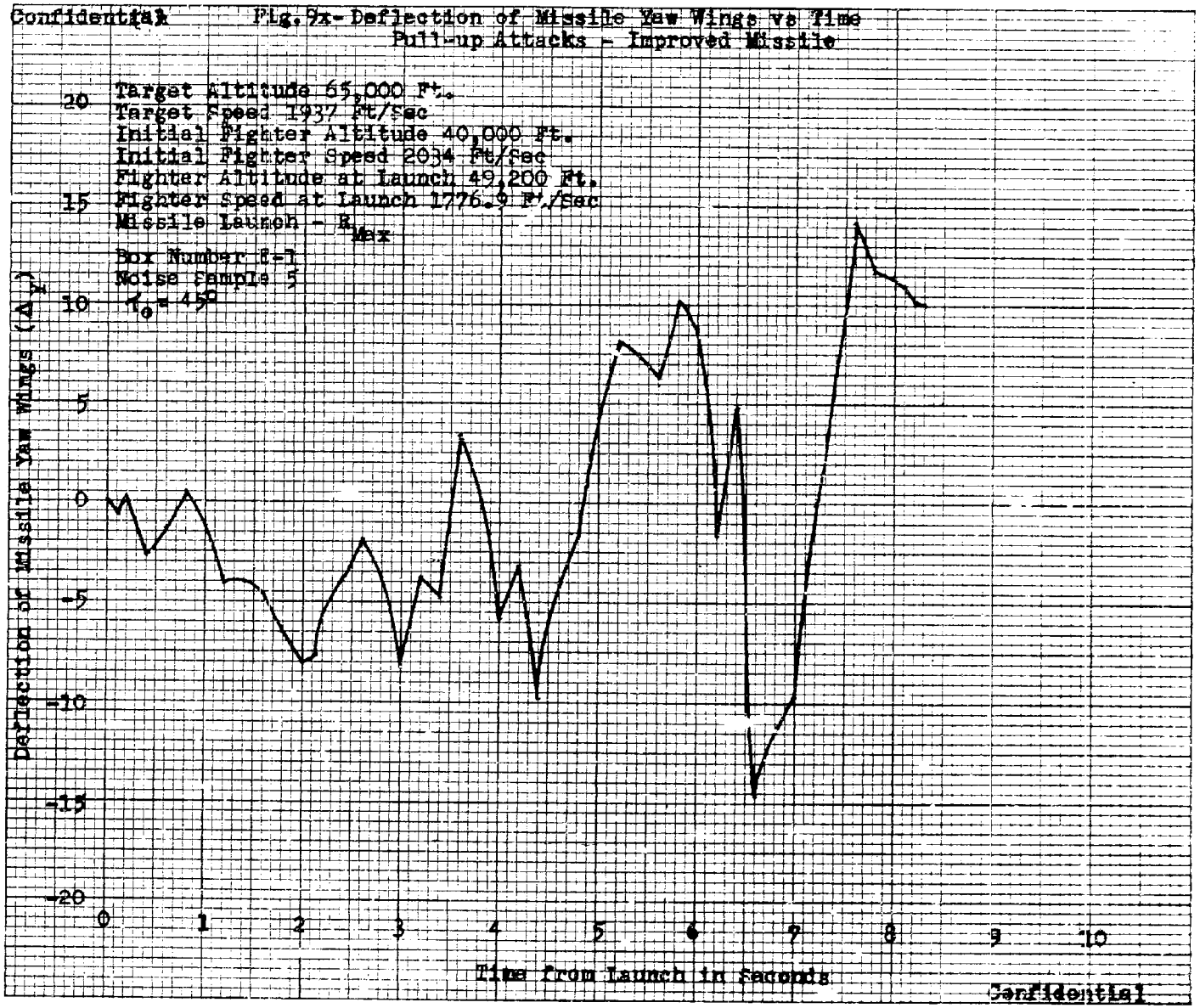
Fig. 7x- Deflection of Missile Yaw Wings vs Time
Pull-up Attacks - Improved Missile



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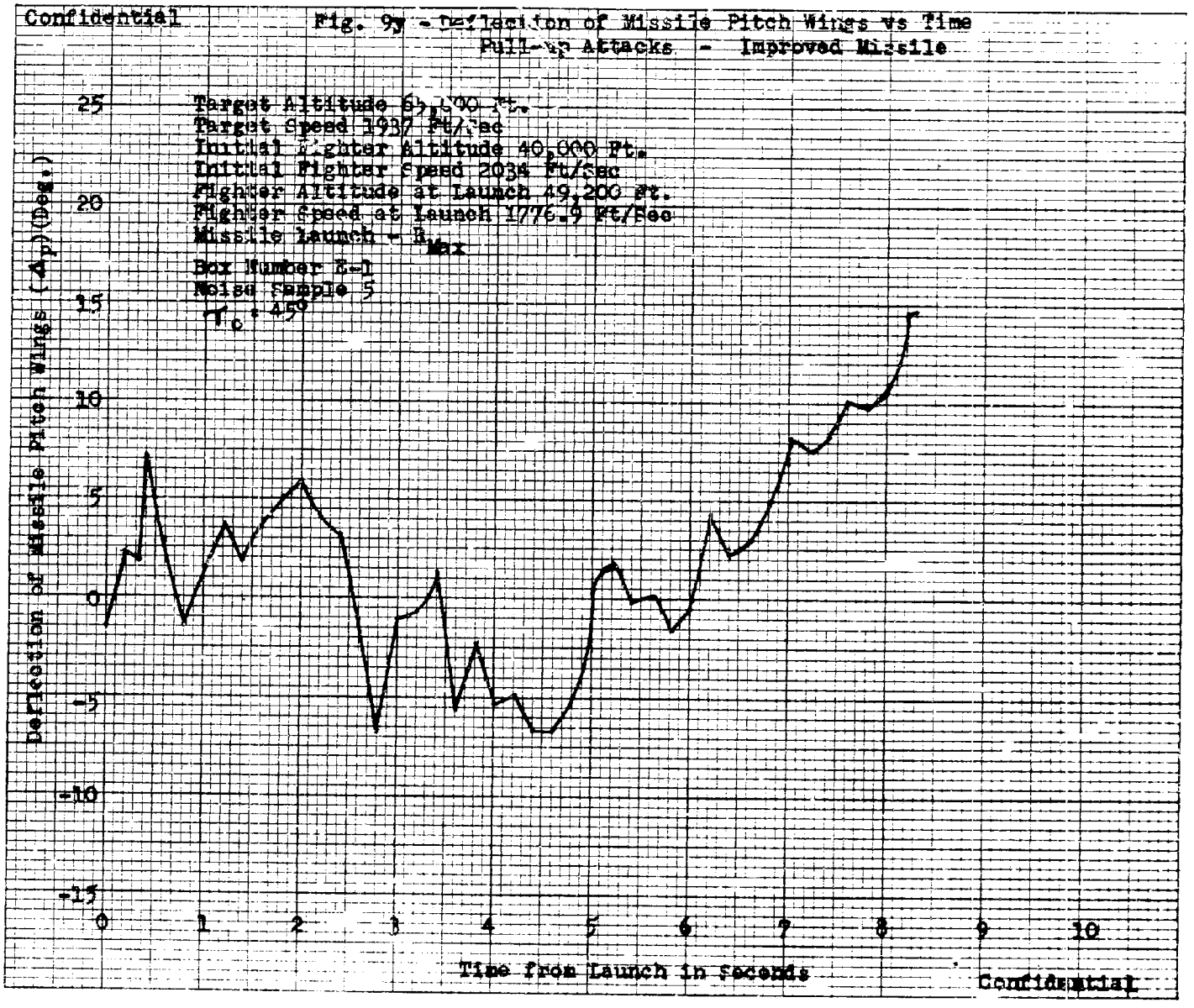

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Fig. 9z -Total Wing Movement vs Time
Pull-up Attacks - Improved Missile

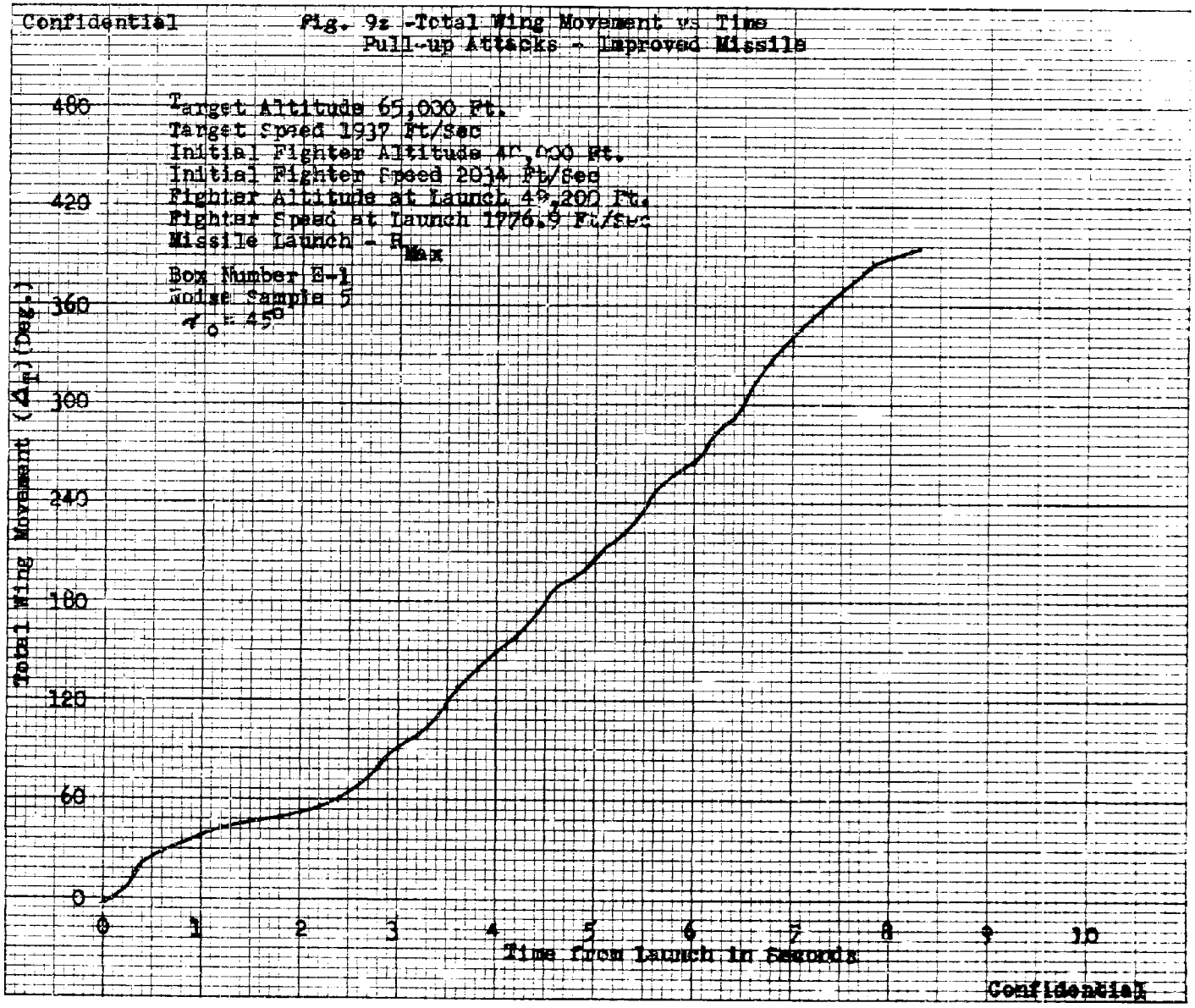

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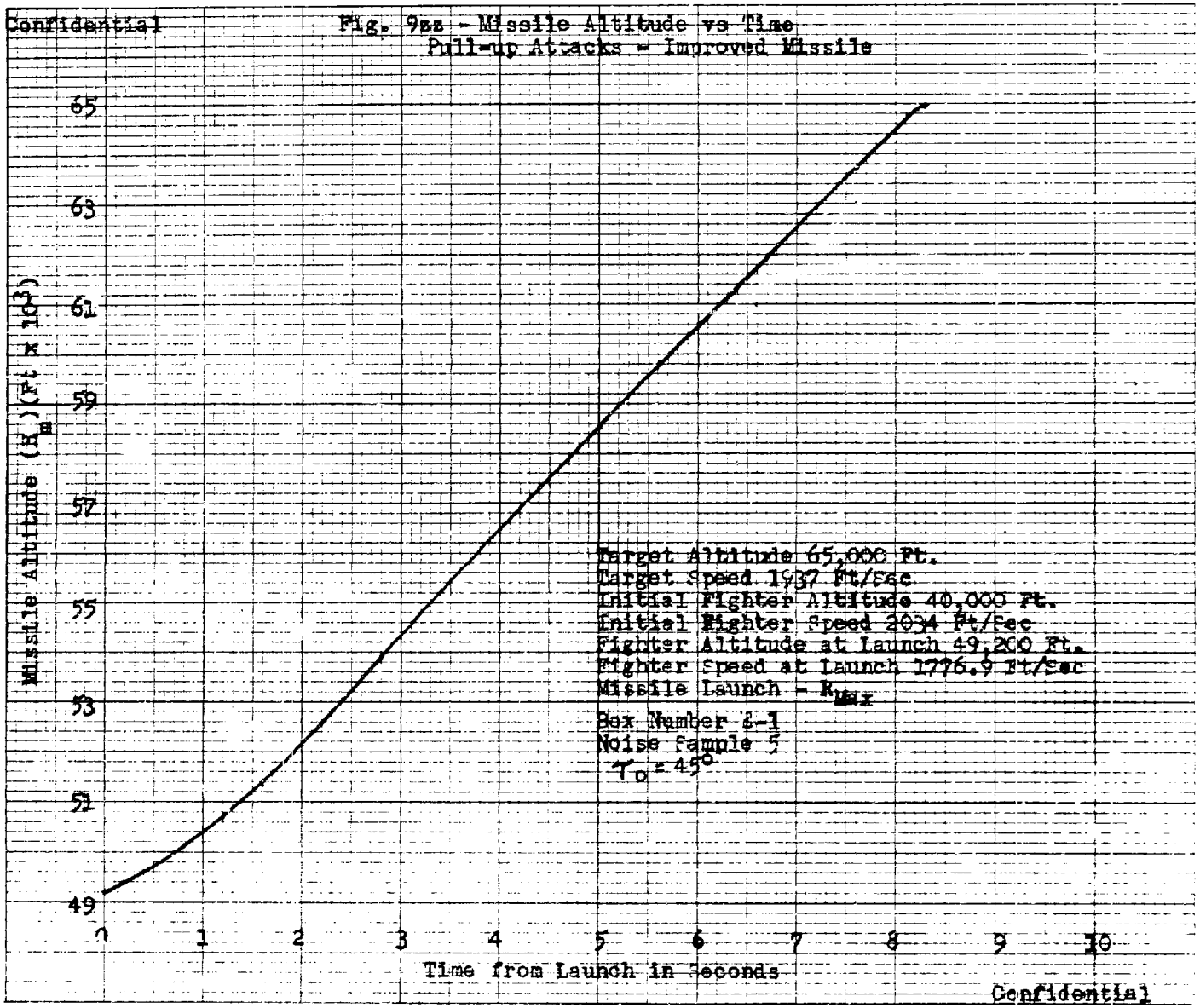
Fig. 9aa - Missile Altitude vs Time
Pull-up Attacks - Improved Missile



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